WATER RESOURCES

THE UNIVERSITY
OF MICHIGAN
AUG 16 1960
MAIN
READING ROOM

HEARINGS

BEFORE THE

SELECT COMMITTEE ON NATIONAL WATER RESOURCES, UNITED STATES SENATE

EIGHTY-SIXTH CONGRESS

SECOND SESSION

PURSUANT TO

S. Res. 48

WASHINGTON, D.C., MAY 26 (afternoon), 1960

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CONTENTS

	Page
American Water Works Association, Task Group 2440R	3903
Brown, Carey H., chairman, American Society of Civil Engineers Liaison Committee	3809
Buckman, H. H., president, National Rivers and Harbors Congress	3867
Oakes, Charles E., chairman of the board, Pennsylvania Power & Light Co. for Edison Electric Institute	3833
Paul, Robert M., executive secretary, Sport Fishing Institute	3813
Robinson, Charles A., Jr., staff engineer, National Rural Electric Cooperative Association	3823
Teller, Dr. Edward, director, Ernest O. Lawrence Radiation Laboratory, University of California	3683

AFTER RECESS

The CHAIRMAN. We are very happy and honored to have Dr. Edward Teller, director of the Lawrence Radiation Laboratory, University of California, Livermore, Calif.

Dr. Teller.

STATEMENT OF DR. EDWARD TELLER, DIRECTOR, ERNEST O. LAWRENCE RADIATION LABORATORY, UNIVERSITY OF CALIFORNIA

Dr. TELLER. Senator Kerr and Senator Moss, it is a very great pleasure and a great honor for me to be here.

I have brought along some material which you might want to study later. I will talk independently of this material, trying to give you the highlights and the points on which you conceivably might want to ask some questions.

We, in Livermore, are working on a number of research projects, one of which is on the peacetime uses of nuclear energy from nuclear explosions.

In this connection, we have found that there are some possible applications to the water resource problem.

Now, I would like to start by saying that we are fully aware of the fact that in this extremely important and complex field we are not experts. We have consulted some experts. We feel, however, that we have a tool which could be very useful indeed and which could make a very great change, particularly in the water-poor regions of our country in the West and in the Southwest.

The simple point is this: Nuclear explosions are, perhaps—I should not say "perhaps"; I should say definitely—the cheapest source of energy which you can have today. You can take them anywhere and place them anywhere. With the help of these nuclear explosions, you can engage in tremendous earth-moving and rock-cracking jobs. We have designated the peaceful use of nuclear explosions as the "Plowshare project."

Our estimate is that for big nuclear explosions, for big earth-moving jobs, the cost of earth moving with help of nuclear explosions is one-tenth to one-hundredth as great as with more conventional earth-moving methods. In some cases, we can move earth for only 1 percent as much as we did by old-fashioned methods. We are so enthusiastic about this that we feel in the future people might engage in something that I like to call geographical engineering; we really can change the surface of this globe to suit ourselves.

Now, in particular connection with the water resources problem, I would like to make a brief remark about two possibilities which exist, but which I think are somewhat more remote possibilities.

We have talked about making containers to keep waste products, particularly radioactive waste.

The CHAIRMAN. Particularly what?

Dr. TELLER. Radioactive waste, to contain waste products in underground cavities.

We have talked about the possibility of using the heat that we have deposited deep underground by nuclear explosions, and then use this heat later for sea-water distillation. This looks like a very difficult and doubtful project which probably will be much too expensive to pay for itself, but even so it is worth thinking about.

There are, however, a number of simple, straightforward earth-moving jobs, and these are the ones on which I really want to talk.

We can make dams, earth-filled dams, wherever they are needed. We can deflect rivers into new paths. We can blast holes in the ground to be used as deepwater reservoirs. And we can crack rock, impermeable rock, so that water can seep into the ground at places where such seepage was previously impossible.

There is no doubt about it. We can do all these things.

However, all the information about the subject, although becoming more and more substantial, is by no means sufficiently clear.

You know that the great majority of nuclear explosions have been executed up on a tower in the air or at best on the surface. We have made only a few truly underground explosions, which are useful for our purposes here. All of these, essentially, have been performed in essentially one material—volcanic ash or tuff, water-saturated tuff, such as you find in our Nevada Proving Grounds.

In order to have sufficient engineering experience on which to base designs of water regulating, engineering activities, we need other explosions in other materials. For instance, we need an explosion in granite. We need an explosion in limestone, which will be quite difficult because it will develop carbon dioxide.

The CHAIRMAN. Develop what?

Dr. TELLER. Carbon dioxide. It will decompose the limestone into carbon dioxide, and carbon dioxide is a gas and we will have some rockheaving qualities, you see.

We need explosions, and we plan to execute one next year, about a year from now, in New Mexico, in salt, which again is a different kind of medium. And we need experiments in alluvial fill, valley fills. There have been two such explosions, but they were exceedingly shallow, and did not teach us enough. We will need more experiments in shale and in other materials.

At present, we are at the beginning of our research and unfortunately are not able to come before you gentlemen and say, "We know how to do these things." I can only say that there is a great potentiality, and we must get started on our research. I know that we can deliver explosive power at a fraction of the cost of conventional explosive power.

Before I go into any further details I would like to tell you of another of our difficulties—our worries. Surely it is perfectly clear that in order for you to evaluate what we can do in a realistic manner, you must be aware of what we are worrying about.

This is the question of radioactive contamination. Now, radioactivity has the same property as everything else in this world. When you have too much of it it is dangerous. Actually there has been a great delusion as to the dangers of radioactivity. It is known that this is a subject about which the danger has been vastly exaggerated. We do know how to control radioactivity.

If we make a nuclear explosion underground we know approximately how far the radioactivity which it will deposit will travel. We ought to continue to study it. In most substances, radioactivity will not travel far. It will stay bound to a relatively small area. More studies of that kind are in progress and are needed.

Furthermore we also know that with a couple of years more of nuclear experimentation, we can develop much cleaner nuclear explosives. These "cleaner" explosives, especially those with tritium, hydrogen, etc., will develop other radioactive sources which will mix with

TYPICAL DIKE COMPLEX
HAWAIIAN ISLANDS
8000
6000
4000
2000
0
-2000
FEET
LEAKS
LAVA FLOWS
DIKE COMPLEX
FRESH WATER
SALT WATER
OCEAN
0
1
2
3
4
5
6
MILES

the water. Again, this is worrisome, but after the passage of a little time and after some appropriate dilution it will get down to safe limits.

Between the possibilities of handling normal nuclear explosions and the better possibility of using this newer and cleaner stuff, I feel quite sure that we can handle radioactivity if we are careful about it, so that no one will have to worry about it.

Now, I would—just to be brief about this whole thing—I would like to give you a very short review of the various uses to which we can put nuclear explosives.

One thing that we can do is to break up rock. With the help of a deep underground nuclear explosion of a 1,000-ton equivalent, we can fracture between 100,000 tons and a half a million tons of rock, and render it permeable. Thereby it is possible to get a seepage of water or a flow of water between a water saturated aquifer and a neighboring dry aquifer.

Unfortunately we are very early in this investigation, and there is only one example which I can give you where we have had a little measure of hope of the application of the thing. I am far from certain that this will turn out to be practicable, but permit me now to go to my exhibit.

Here is the northern end of the big island of Hawaii. This is Mauna Kea. The trade winds come from this general direction [indicating]. This side of the island is wet. The other side of the island is dry, much more dry, and furthermore the rainfall is seasonal. The sugar plantations are at this spot, which I think is invisible to you—I have marked it with a little red cross. The sugar plantations here use water which has been deposited in the mountains here.

Now most of this mountain is quite spongy, quite permeable, but it is crisscrossed in a fashion like this, with water catching water, impermeable competent layers of volcanic intrusions, dikes.

Here is this wet layer, the dark color indicates it, whereas the dikes are shown as the lines here.

What people in Hawaii did was to drive a tunnel into this wet layer and get quite a bit of water out to water their sugar fields.

Now, it would be possible to shatter these layers and get much more water out of it, but of course we have never shattered this kind of volcanic rock before. It would have to be done first elsewhere, on an experimental basis. We would have to know beforehand how much radioactivity would get into the water, because otherwise we might spoil a good situation, rather than improve it. I feel very confident that with sufficient preliminary experimentation, there is an excellent chance to multiply greatly the water in this particular location.

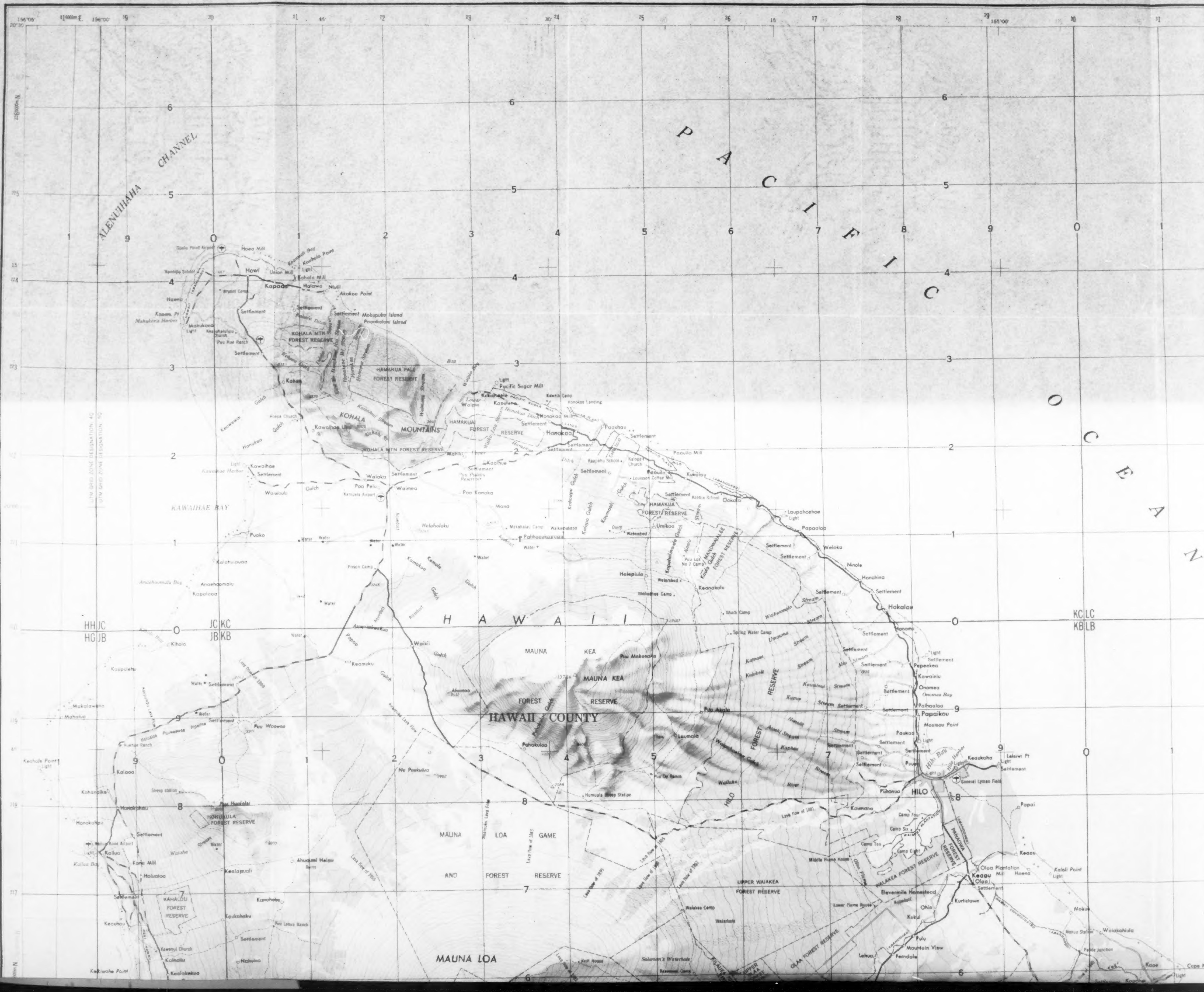
I do not want to give you the impression that this is the only example of subterranean water which we so can regulate. I have discussed it merely as one example, but I am sure that there are many others.

Now, we have discussed also the possibility of diversion of rivers so that instead of flowing into the ocean on a short route, and wasting the water, it should flow to regions which need water. I have no concrete proposal to present to you gentlemen on this. There is one which looks to me excellent, but unfortunately, it is not in our country. It is in Australia, where the most abundant rainfall is east of the divide, which is close to the Pacific and just west from this divide there is an artesian basin which could contain water and could be used if there only would be rainfall. The Australians want very

HAWAIIAN ISLANDS 1:250,000

HAWAII NORTH

FIRST EDITION-AMS



FIRST EDITION-AMS

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AMS SERIES W532

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45'
154°35'
20°30'
330000m E.
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225
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PACIFIC OCEAN

KC LC
KB LB

Honohina
Settlement
Hakalau
Honomu
Settlement
Light
Settlement
Pepeekeo
Kawainiu
Settlement
Onomea
Onomea Bay
Paihaaloa
Papaikou
Maumau Point
Paukaa
Light
Settlement
Settlement
Puueo
Hilo Bay
Hilo Harbor
Hilo Light
Keaukaha
Leleiwi Pt
Light
Settlement
Light
General Lyman Field
Pinnonua
HILO
Papai
Camp Four
Camp Six
Camp Ten
Camp Eight
WAIAKEA PLANTATION
WAIAKEA FOREST RESERVE
PANAEWA FOREST RESERVE
ABANDONED
Keaau
Olaa Plantation
Mill
Haena
Kaloli Point
Light
Keaau
Olaa
Settlement
Elevenmile Homestead
Aqueduct
Kurtistown
Ohia
Kukui
Makuu
HAWAII CONSERVATORY
ABANDONED
Makuu Station
Waiakahiula
Pulu
Mountain View
Ferndale
Pahoa Junction
Kaoe
Cape Kumukahi
Light
Settlement
Kapoho

AMS W532
First Edition AMS

Prepared by the Army Map Service (AMS-AS), Corps of Engineers, U.S. Army, Washington, D. C. Compiled in 1951 from Territory of Hawaii Quadrangles, 1:62,500, and AMS 1:50,000, U.S. Geological Survey, 1913-28; U.S. Coast and Geodetic Survey Chart No. 8115, 1942; and miscellaneous data to 1951. Planimetric detail partly revised by photo interpretation methods. Road, railroad, and astronomical data verified by territorial authorities. Control by U.S. Coast and Geodetic Survey.

POPULATED PLACES
- 100,000 or over
- 20,000 to 100,000
- 5,000 to 20,000
- 1,000 to 5,000
- 1,000 or less

Railroad, Normal gauge (4 feet 8½ inches) — Multiple track
County boundary
Reservation boundary
Horizontal control point
Spot elevation in feet
Crevice
Landmark feature

LEGEND

HONOLULU
HILO
LIHUE
Pahala
Honamu

Hard surface, all weather roads
- More than two lanes wide
- Two lanes wide
- Less than two lanes wide

Loose surface roads
- Graded, all weather
- Dry weather or dirt

Trails
Tracks
National route marker
Secondary route marker

Landplane airport
Landing area
Seaplane airport
Seaplane anchorage
Woods-brushwood
Rocks: Sunken; Awash
Marsh or swamp
Reef; Limit of danger
Foreshore flats
Depth curve in fathoms

Scale 1:250,000

5 0 5 10 15 20 Statute Miles
5 0 5 10 15 20 25 30 Kilometers
5 0 5 10 Nautical Miles

CONTOUR INTERVAL 200 FEET
VERTICAL DATUM IS BASED ON MEAN SEA LEVEL

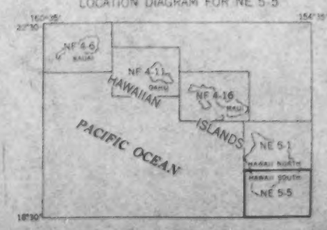
TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM IS BASED ON OLD HAWAIIAN DATUM

BLACK NUMBERED LINES INDICATE THE 10,000 METER UNIVERSAL TRANSVERSE MERCATOR GRID ZONES 4 AND 5 INTERNATIONAL SPHEROID

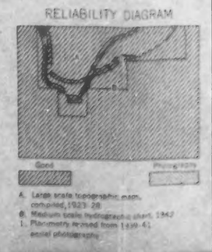
THE LAST FOUR DIGITS OF THE GRID NUMBERS ARE OMITTED
1951 MAGNETIC DECLINATION IS 11°00' EASTERLY FOR THIS SHEET
MEAN ANNUAL CHANGE IS 0°01' EASTERLY

USERS NOTING ERRORS OR OMISSIONS ON THIS MAP ARE URGED TO MARK HEREON AND FORWARD DIRECTLY TO COMMANDING OFFICER, ARMY MAP SERVICE, WASHINGTON 25, D. C. MAPS SO FORWARDED WILL BE RETURNED OR REPLACED IF DESIRED

LOCATION DIAGRAM FOR NE 5-5



RELIABILITY DIAGRAM



A. Large scale topographic maps, completed, 1923-28
B. Medium scale hydrographic chart, 1942
C. Planimetry revised from 1939-41 aerial photographs

Scale 1:250,000

10 15 20 Statute Miles

10 15 20 25 30 Kilometers

5 10 Nautical Miles

CONTOUR INTERVAL 200 FEET

DATUM IS BASED ON MEAN SEA LEVEL

LAMBERT CONFORMAL CONIC PROJECTION

DATUM IS BASED ON OLD HAWAIIAN DATUM

UNIVERSAL TRANSVERSE MERCATOR GRID ZONES 4 AND 5, INTERNATIONAL SPHEROID

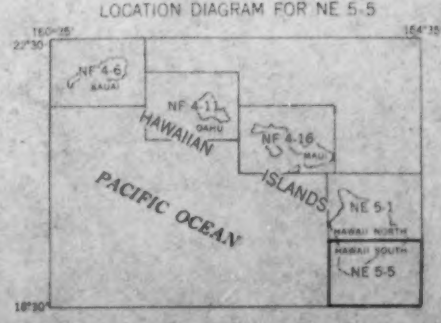
TICKS OF THE GRID NUMBERS ARE OMITTED

DECLINATION IS 11°00' EASTERLY FOR THIS SHEET

ANNUAL CHANGE IS 0°01' EASTERLY

USERS OF THIS MAP ARE URGED TO MARK HEREON AND FORWARD DIRECTLY TO COMMANDING OFFICER, U. S. ARMY MAP SERVICE, WASHINGTON 25, D. C. MAPS SO FORWARDED WILL BE RETURNED OR REPLACED IF DESIRED

LOCATION DIAGRAM FOR NE 5-5



RELIABILITY DIAGRAM

A. Large scale topographic maps, compiled, 1923-28
B. Medium scale hydrographic chart, 1942
1. Planimetrically revised from 1939-41 aerial photography

PRINTED BY ARMY MAP SERVICE, CORPS OF ENGINEERS, S-53, 757569

SHOWN IN BLACK

HG	JB	KB	LB
HF	JA	KA	LA

210 (10 10)

205,000

HAWAII SOUTH, HAWAIIAN ISLANDS

badly to divert their rivers, and that is the type of situation where it could be very helpful.

We have learned about a general situation in the Southwest which we are now looking into. Some of our good friends who know more than we do are looking into it, for it is a strange situation. There is the possibility of diverting rivers in order to throw their water away. We understand that in the Southwest, in western Texas, for instance, there are many cases where you have springs of very high salinity which, when they mix with the other water flow, degrade or spoil the quality of that water. So, in these cases, it would be a good idea to divert these rivers, lead them off into regions where they can seep into the ground, in regions which are already highly mineralized, and therefore useless.

The CHAIRMAN. You mean to divert the salt water part of it.

Dr. TELLER. Divert the salt water so that it will not do any mischief or to make a place for it in basins where the salt water can be contained and evaporated and then, therefore, be made harmless.

Similarly one might, when the ground water is too salty, make some blasting underneath the salt water and let it sink deeper into the ground so that again it should be out of the way of mischief.

This to my mind is a particularly attractive possibility, because here we use this to throw away some undesired water, and therefore, the problems of contamination by this undesirable water is by no means as important and as harmful as would be the case if it would be operating on more useful water. But, with proper care, we can make basins and we can divert sweet water and useful water, as well.

Now, among these various possibilities, there is one in which I am particularly interested. In one of our shots in Nevada, which was a nuclear shot on the slope of a mountain, this nuclear shot threw out quite a bit of earth which then came down the slope for a certain distance. This kind of procedure could be used to make an earthfilled dam.

Now it so happens that nature has provided us with some experience about such earthfilled dams. There are examples of them in Wyoming, and my other map here refers to these examples.

Quite a few years ago an earthquake created a dam here on the Gros Ventre River, and this had produced a big lake. The dam held for approximately 2 years, then it gave way—at least the top of it did. Then there was a considerable, but smaller, lake left held by the lower residual part of this dam. This is called the lower slide lake.

The reasons why such earthfilled dams give way are multiple. One is that water spills over their top, erodes the top, makes a new channel that caves in. In the absence of a good spillway the dam just will not hold it. Secondly, the bottom of such a dam is usually not sufficiently cemented to what is lying underneath, and water may eat its way through the bottom, wash it out, and the water flow become more rapid and it is a self-propagating process and the whole dam might come down.

There is a very interesting example which occurred during the recent earthquake just west of Yellowstone Park, back on the Madison River.

I will leave this map with you.

Here is a region which I have crosshatched in black on the map. This is a naturally produced earthfilled dam about 10 times as broad as you would construct it if you would do it in an engineering manner.

It is just downstream from Hebgen Lake. Behind the dam there has been formed a lake which we call Earthquake Lake.

Now, in this case we did not neglect the situation as we did on the Gros Ventre River. I believe that a spillway was built on top of this new dam thereby lowering the level of the lake, and it also introduced a situation which we now hope will allow this lake to last and be useful for very many more years. The lake which now exists, the little region here, is for your reference crosshatched in red.

I would like to say that in my opinion, with the help of nuclear explosions, we can do much better than nature has done. We can prepare the ground so that the earthfill will come down on more solid material. We can make the earthfill big enough so that the water will not spill over the earthfill, but rather would spill on an entirely different path. These would be new and different paths which were originally dry, which we coud prepare ahead of time, with a proper spillway, with a proper water intake, and hydroelectric equipment which you may or may not want to put there.

Then the earthfilled dam itself would have to be keyed to the ground, well prepared, and in this way I am quite sure that we can do a very good solid job of construction.

Now, a nuclear explosion, according to present estimates, will cost from a half million dollars to $1 million. If it is small, in the neighborhood of five or ten thousand tons, it will be half a million dollars. If it is big, in the neighborhood of a million tons, it will cost $1 million.

The kind of slide which occurred near Earthquake Lake, we estimate we could produce with 300 tons of TNT. The cost of it at present would be approximately $1 million. But I think that if we increase our research efforts and our experiments, we would find a little cheaper way of doing it.

Now, what this might lead to, I do not know. Whether it will work in the erection of big dams or small dams I do not know. We can make big dams, but we also can make smaller dams in inaccessible spots, and quite a bit cheaper than we could make them in the past.

I am not arguing, therefore, that we should go in the direction of big dams or small dams. I merely say here is something we have to develop.

Now one more remark. The Russians are doing these things. They have made several nuclear-sized explosions in Tashkent and elsewhere, to make waterholes to deflect rivers. They claim they have done it with high explosives. We know that at the size they are beginning to operate, and which they say they will increase, it is more economical to use nuclear explosions. They have not invited us to see this, so that we can verify whether it has been done with high explosives or nuclear explosives.

In the long run I am sure, if they want to conduct their operations economically, they will be driven in the direction of nuclear explosives, and they are, perhaps, ahead of us in the technique of using such explosives.

I will finish by saying that if we want to go ahead with this possibility, here is a great opportunity for water regulation. What we need are experiments to find how we can shatter and move the different kinds of substances of rock and earth. Our experience so far has been limited.

We furthermore need permission to develop nuclear explosives which are as clean as possible, so as to get rid of as great a portion of the radioactive problem as is possible.

There is considerable interest already in this project and our present work is not particularly limited by funds. More funds are always welcome, but our present work is limited by politics.

The CHAIRMAN. By what?

Dr. TELLER. By politics.

The CHAIRMAN. Yes.

Dr. Teller. By the fear of people, by their worry of using nuclear explosives for anything, by their worry of what the Russians will say if we do it.

We feel that in this peaceful application of nuclear explosives, in this project "Plowshare," and its possible use for the regulation of our most valuable resource, water, if we are not to miss the boat, we should try to get your help to investigate this question very carefully. We must make the proper experiments for the peaceful use of our nuclear tools.

This, I say, gentlemen, is the substance and details, and more careful language will be found in the report, that is before you, and in the supplements which I have submitted with the report.

The CHAIRMAN. Thank you very much, Dr. Teller. Your report will be made a part of the record, in addition to your remarks.

What you have told us is of the greatest interest, especially what you have said about being able to accomplish these desirable objectives without having to neutralize, insofar as uses of water is concerned—the radioactive contamination.

As I have understood you, you have expressed complete confidence in being able, through research and experimentation, to develop the specifications of the required nuclear explosive which can be used without creating dangerous radioactive contamination.

Dr. TELLER. That is right, sir. I think, under certain conditions, we can use our present tools, but we need experimentation in various geological surroundings to make quite sure that indeed we will not cause damage.

In other cases, we need these cleaner tools, which we know how to develop, but which have to be developed by nuclear experimentation, in order for them to be used again in such a way as to be sure that we do not expose anybody to more radiation than has been specified to be safe by our general standards. And I can assure you that the standards, indeed, are safe. They are, in fact, more or less geared so that nobody should be exposed essentially to more radiation than he gets, anyway, from cosmic rays and from the background, the radioactive rocks, and from the little radioactivity that is—in any case—in his body and in his food intake.

The CHAIRMAN. Any questions, Senator?

Senator Moss. Dr. Teller, do I understand that you are not really limited by funds now, in this experimental field, but you are limited by the ban against nuclear explosions; is that right?

Dr. TELLER. Of course, sir, I am sure that it is clear to you that one is always limited by funds. But the actual fact is, if we could use our present funds to their full advantage, we would go much faster. Furthermore, there is enough interest in the Atomic Energy Commission and other agencies, that I am sure that if the political considerations would disappear, then we would have available to us funds which would no longer limit ourselves.

I think our first limitation is politics, our second limitation then will become probably manpower and experience, because we will not be able to go ahead with any of these very important projects until we have first selected the right site in a very careful manner; and only then will the big job lie ahead of us. I feel that the main limitation today is the fear of the bomb and not funds.

Senator Moss. You talked about using the nuclear explosion to shatter rock. Is it possible also to fuse rock and in that way use it to be more structurally strong?

Dr. TELLER. Possibly, sir. I do not know. Let me tell you what I do know.

We have made underground explosions in this volcanic ash which has a porosity of approximately 20 or 25 percent, the pores being filled with strongly held water and the material consisting of silicates. In this material our first and typical explosion was a 1,700-ton TNT-equivalent nuclear explosion. In either event it is described in detail in one of the appendixes which I have handed to you. The nuclear explosion blew a spherical hole into this of a diameter of 110 feet. This was lined with 4 inches of thickly fused material. We estimate that in a time between 30 seconds and 120 seconds this cavity collapsed.

The fuse drop contained most of the radioactivity. This radioactivity now is not in this sphere, in the shell, nor is it at the place where the explosion had been fired, but in a cup into which this sphere has collapsed.

It is quite possible that in another material, like limestone or granite, a cavity with strong-fused walls would be created. I am not at all sure that this will happen.

If you would offer me a bet on even money, I would perhaps bet against it; however, it is the type of thing that we do not yet know. We have shattered this type of rock. It held itself so strongly that it was holding water permanently.

After a shot, a lot of it became temporarily easily permeable to water; or, at least, it so appeared. Whether in granite we will make a water impermeable layer, and maybe beyond it a fracture in water permeable zone, or whether we can do something else, I simply do not know.

These are the experiments which we have to carry out. I feel certain, however, that some materials will be able to shatter, at least, and in one case we have done it. I feel certain we can form craters and basins.

I am sure that we can cave in steep mountainsides, and therefore we can perform some important jobs. As to how many, how, what engineering specifications are needed, we are just beginning to develop means of finding the answers. If you give us your support and your encouragement, which is essentially what we need, and maybe later your financial support, too, I think that the result will be that 2 years from now or 5 years from now we can come back to you with a sound and safe program.

Senator Moss. Thank you very much, Dr. Teller. Your testimony certainly is interesting and I appreciate it very much.

Thank you, Mr. Chairman.

The CHAIRMAN. You have made a great contribution to this committee, Doctor. Your statement and the five appendixes will be included at this point.

Dr. TELLER. Thank you.

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Livermore, California

SOME POTENTIAL USES OF NUCLEAR EXPLOSIVES IN THE CONSERVATION AND DEVELOPMENT OF WATER RESOURCES

May 24, 1960

3691

ABSTRACT

The peacetime application of nuclear explosives to the conservation and development of our national water resources is, at this time, of sufficient promise to present some of the possibilities publicly. In nuclear explosives man has at his disposal and service, a powerful source of energy – a new tool – that we believe can be utilized safely to excavate channels and lake basins, or to create conduits of broken permeable material and underground reservoirs. In surveying the possible applications of nuclear explosives, the following ideas are among those worthy of serious consideration: (a) the use of nuclear explosives for the economic movement of large volumes of earth in the construction of earthfill dams, (b) the use of nuclear explosives for the diversion of a stream from a river system, whose flow is largely lost to the sea, into another stream channel leading to an arid section or a closed basin, (c) the use of nuclear explosives to create a recharge basin or a conduit to a subsurface aquifer for fresh water recharge, and (d) the use of nuclear explosives to create off-channel reservoirs for the elimination of saline waters through recharge to a mineralized aquifer and by evaporation.

Although the Lawrence Radiation Laboratory is expert in the development of nuclear explosives and in the analysis of the effects of explosives on the surrounding media, other relevant fields need to be explored, such as engineering, geology, and geohydrology. It is with the hope of enlisting the aid and interest of the fellow scientists, engineers, and others interested in water conservation that we prepare this report. The future exploration and development of peaceful uses of nuclear explosives in the field of water resources will require an inter-disciplinary effort.

3692

CONTENTS

		Page No.
I.	Introduction	3
II.	Nuclear Explosions	4
III.	Principles of Radioactivity Control	6
IV.	Underground Storage and Underground Diversions	10
V.	Surface Reservoirs and Diversions of Surface Water	12
VI.	Earthfill Dams	14
VII.	Saline Water Conversion	19
VIII.	Soviet Experience with Large Explosions	20
IX.	Present Knowledge of Explosion Phenomenology	21
X.	Costs and Conclusions	23

I. INTRODUCTION

The water problem in the United States today is becoming increasingly serious, especially in the western and southwestern portions of the country. It is therefore important that we explore every means at our disposal in order to be able to employ our existing resources as efficiently and constructively as possible. In the search for new tools and new techniques, the potentialities of nuclear explosives have not heretofore been discussed publicly to any great extent.

During the last several years scientists at the Lawrence Radiation Laboratory in Livermore, California, have been studying possible uses of such nuclear explosive techniques for peaceful purposes, including the improvement of water resources. We are considering both surface and underground water developments, primarily with a view towards achievements for the long run. We are aware, of course, of the problems associated with the control of residual radioactivity; we have therefore undertaken a number of studies to increase our knowledge of the control of radioactivity. While we do not in any way minimize the importance of protecting the public from radioactivity and its effects, we believe that, with further experimentation, we can utilize nuclear explosives in a water development project without significant hazard to either present or future generations. We also recognize that, while we at the Lawrence Radiation Laboratory are expert in the development of nuclear explosives and in the understanding of the interactions between nuclear explosives and the surrounding media, we are not trained in many of the other relevant fields of knowledge. Therefore, we have consulted, and will continue to consult, recognized authorities in engineering, geology, geohydrology, and water resources in order that we may intelligently evaluate sites, experiments, and potential benefits from this program.

48186 O—60—pt. 23——2

II. NUCLEAR EXPLOSIONS

Ever since the first nuclear explosion, in 1945, nuclear scientists have been looking for ways to utilize, for peaceful purposes, the extremely high energy concentrations available in the atomic bomb. More recently, the results of underground nuclear tests at the Nevada Test Site have shown that changes in both surface topography and the subsurface structure can be induced by appropriate placement of the nuclear explosive.

The first underground nuclear explosion, Rainier, was detonated in volcanic tuff at a depth of 790 feet from the nearest surface. While it was a small event (1.7 kt), as nuclear explosions go, it was large enough to cause profound changes in the material around the shot point (see Appendix I). During the first few milliseconds after the detonation, the ball of hot gas expanded to a radius of about 60 feet, sending a strong shock wave ahead of it, which crushed the material out to a radius of about 130 feet and sent many cracks to more than twice that radius. After the cavity collapsed, in 1/2 - 2 minutes, the failure of successive layers of rock above it resulted in a broken zone (chimney) some 400 feet in height and about 100 feet in diameter. There was no radioactivity detected on the ground surface and no evidence of significant permanent displacement above the shot point.

It is this picture of a completely confined nuclear explosion which leads us to believe that we may be able to make a contribution to the solution of problems in the flow of underground water. For, as an immediate result of each detonation in the tuff, much of the region above the shot point, originally of very low permeability, was transformed into a broken volume through which water would probably flow more readily. At the same time the permeability of the material directly below the shot point and at the sides of the cavity was still quite low. A nuclear explosion in another medium may,

of course, behave differently. But, in favorable areas, it is likely that the permeability of a fairly large region above the shot point can be increased by a nuclear explosion. We therefore expect that we can break up a relatively impermeable layer of rock to form a conduit to lead water from the surface to an underground area or from one underground site to another.

On October 14, 1958, another underground nuclear explosion (Neptune) was set off. In this event, the detonation of a 110-ton nuclear explosive in volcanic tuff resulted in the throw-out of 45,000 tons of rock, leaving a crater 150 feet wide, 200 feet long, and 40 feet in depth. In this process less than 5% of the gross radioactivity escaped to the surface. It is reasonable, then, to expect that we can create artificial lake basins and channels for water flow by the use of these explosives. Since we can still get useful craters with only a small percentage of released radioactivity, it would appear that the alteration of surface topography to create reservoir sites and infiltration basins is a possibility worthy of investigation.

III. PRINCIPLES OF RADIOACTIVITY CONTROL

One of the most important considerations in the use of nuclear explosives is, of course, the control of radioactivity in order to guarantee public safety. When a nuclear explosive is detonated, radioactive fission products are released and other less abundant radioactive materials are formed by the interaction of escaping neutrons with the surroundings (see Appendix II). The use of thermonuclear explosives and a neutron-absorbing blanket can significantly reduce both the fission product and induced radioactivity. However, the residual tritium from the thermonuclear explosives may further complicate the problem. The isotopes produced in a fission explosion are essentially the same as those produced by nuclear reactors; one kiloton of fission yield produces about the same amount of radioactivity as one day's operation of a 55 megawatt reactor.

There are two different types of radioactive hazards produced by fission products. One kind results from the residual γ-radiation field, which, like an x-ray beam, penetrates even massive objects which lie close to the radioactive debris. Essentially no radioactivity is induced in objects irradiated by this field, and, in this residual γ-radiation field, the effects produced are proportional to the time spent in the field and to the intensity of the field. The second kind of radioactive effect which can be produced by fission products arises when they are ingested by humans from water and food, so that the short-range ionizing particles are able to cause internal damage. The effects of Sr^{90} are of this nature.

The general radiation field is produced by radioactive materials which reach the ground surface when an explosion is not fully contained (e.g., in the creation of surface storage reservoirs or recharge basins). The most obvious, and the most important, means of controlling this radiation is to

prevent unintentional human access to the radioactive area until the radiation field has had time to decay. In most of the applications so far considered, the decay would not take more than about one year, even if all-fission nuclear explosives are used; during that time, careful monitoring and control of the entry and exit of personnel, material, and water would be necessary. After the radiation field has decayed to a safe value, as determined by measurements of radioactivity, free and unrestricted access could be allowed. No residual γ-radiation field of this kind would be produced if the debris from the explosion were not permitted to reach the surface of the earth; even when the explosion is designed to produce a crater or a channel, not more than a few percent of the radioactivity would be found on the surface.

The second type of radioactivity effect, that due to a longer-lived isotope which may be ingested and thus cause internal damage, is a little more difficult to assess. Its magnitude depends strictly on the details of the geology, the ground water disposition, and other characteristics of the specific site of the detonation, as well as on the amount, the nature, and the disposition of the radioactive material. As discussed in Appendix II, most of the radioactivities which are produced in the explosion are trapped within a few feet of the shot point. Since the potentially dangerous radioactivities, in this sense, are those which have relatively long half-lives (e.g., Sr^{90}, with a 28-year half-life), it must be ascertained not only that the water and the area are safe immediately following the explosion, but that the water will be safe for periods as long as several centuries. Therefore, even though the radioactivities are bound in slag and on the surfaces of rock, which can prevent their reaching the human population at early times, their further behavior must be predicted.

Fortunately, it appears that, in some rock and soil types where relatively pure water is in contact with radioactive substances, the radioactive atoms

are so strongly adsorbed by earth materials that they migrate very slowly, even in reasonably rapid water flow (see Appendix III). The radioactivities in favorable areas generally migrate at rates less than 1/100 the rate of flow of the water. For example, for a ground water velocity of 500 feet per year the radioactivity in such an area will move not more than one mile every 1,000 years. Essentially all of the Sr^{90} from a nuclear explosion will have decayed after 1,000 years. This second kind of hazard can be evaluated in detail only in connection with a particular experiment. If the geology and the properties of ground water flow at the proposed site are well-known and are favorable, we believe, on the basis of present information, that nuclear explosive techniques can be used safely. In some situations, for example, the water must pass through beds containing clay minerals, with their large adsorption factors. Other projects permit the location of the explosion to be such that water going to beneficial use would not come into contact with most of the radioactivity. In this second circumstance, the few percent of the radioactivity which gets into the broken region above the shot at the time of the explosion can be filtered out or made harmless by dilution. Naturally, tests of the effectiveness of these modes of control of radioactivity will be needed, but there is little reason to believe that they will not work.

Another study which will lead to improved control of radioactivity is the development of low-fission explosives, in which the major portion of the energy comes from fusion reactions, rather than from fission. The use of these clean explosives may prove advantageous wherever the associated tritium can be properly controlled. The Laboratory has for some time been working on the design of such clean nuclear explosives for Plowshare applications.

In summary, we believe that these novel techniques can be used safely if appropriate precautions are taken. The detailed geology and the flow

pattern of the ground and surface water must be satisfactory for each proposed site; any location with highly mineralized water or very soluble rock types would introduce additional problems. Comprehensive laboratory studies should be conducted with samples of water, the minerals, and the soils from a proposed site to determine whether the radioactivities characteristic of nuclear explosives would be very strongly adsorbed by the rocks and soils in the vicinity of the detonation. Finally, no withdrawal of water from the area should be permitted unless tests indicate that the water is safe.

IV. UNDERGROUND STORAGE AND UNDERGROUND DIVERSIONS

In this section we shall examine a number of potential applications of explosive nuclear energy to the problems of underground water movement. While the economic and legal feasibility of any of these suggestions will depend crucially upon the site chosen for the project, the technical aspects can be discussed in a more general framework, without reference to a specific location. It will be convenient to divide the goals into three categories:

1. Transport of fluids from subterranean regions to the surface;
2. Transport of fluids from one underground place to another; and
3. Transport of fluids from the surface downward into an underground storage area.

Nuclear explosives can assist in the transportation of water to the surface by creating pumping basins. In an aquifer of relatively low permeability, the use of a nuclear explosive either in the aquifer layer itself or in a competent layer beneath to create a fairly large volume of high permeability would appear to be feasible. Since the area available for infiltration of water into the pumping basin would be much larger than that normally available in a well, the well yield could be noticeably expanded.

Another group of potential applications of nuclear explosives to water resource problems is their use to break underground barriers. For example, in a volcanic region of high but seasonal rainfall, water may be confined by a set of more or less vertical dikes. It travels downward and eventually reaches the sea. If we can puncture these barriers, we can tap this water, which would not otherwise be utilized. In addition to this "one-shot" benefit, any recharge of water into the newly accessible region would thereafter contribute to the water supply of the area. Barriers to horizontal water flow also occur in non-volcanic regions. If it should prove advantageous, these barriers,

too, can be pierced permanently in order to capture water which would not normally be used.

Finally, let us look at two examples of the third objective. In a region of high water cost and high evaporation rates, a nuclear explosive can be employed to create underground storage space. Such a reservoir would contain about 4,000,000 gallons of water per kiloton of yield, according to our present knowledge of the scaling laws, and would have negligible evaporation losses. In the course of making the volume for storage, the explosion might also provide a conduit through overlying impermeable rock, as the failure of successive layers of weakened rock might create a cylindrical volume of very high permeability. Precisely this example of the use of nuclear explosives has been studied by members of the Laboratory staff in connection with San Clemente Island. While such an experiment may be technically feasible, other considerations suggest that we not propose its execution at this time.

Another application of this basic idea would be the creation of storage volume at depth for the disposal of radioactive waste products from nuclear reactors. By deep burial these noxious materials can be kept out of the biosphere permanently.

V. SURFACE RESERVOIRS AND DIVERSIONS OF SURFACE WATER

Nuclear explosives can also be used profitably in connection with the development of surface water resources. Four possibilities stand out:

1. The diversion of low quality water from a stream channel to an off-channel reservoir, where the undesirable water can be eliminated by evaporation and/or by infiltration into an existing aquifer containing low quality water;
2. The diversion of desirable waters for gravity recharge;
3. The creation of deep lakes; and
4. The improvement or alteration of stream channels.

The first of these is suggested by the fact that the headwater tributaries of many rivers of the Southwest contain undesirable or brackish waters during the low spring flow period. These saline waters are, in many cases, transmitted by the existing stream system to retention reservoirs, where the quality of water is degraded by their addition. The creation (either by the use of nuclear explosives or by conventional means) of off-channel reservoirs for the diversion of these undesirable saline flows would serve two functions:

1. A large evaporation pond would be formed, from the surface of which water would evaporate; and
2. The reservoir could serve as a conduit to transmit water from the artificial channel to an underground aquifer which is already mineralized.

With the aid of these two mechanisms the low saline flow of headwater tributaries may well be eliminated from the stream system, permitting greater beneficial use of the remaining fresh water. If the low-quality water is located in an area of extreme water need, it might even be salvaged by a demineralizing process. If, on the other hand, the impounded brackish waters are to be

eliminated by evaporation and infiltration, the effort necessary to maintain an effective infiltration surface would be minimal, in view of the small sediment load associated with the low volume spring flow.

The second idea, the diversion of desirable waters for gravity recharge, is similar in nature to the first. A portion of the stream flow could be diverted to an off-channel reservoir for gravity recharge to a subsurface aquifer. Here, underground, the water could be retained and stored for future use without the high evaporation losses normally suffered in the case of surface storage. There are, however, a number of engineering problems which would have to be solved in the development of this suggestion.

The third concept relates to the storage of water in especially-constructed deep lakes designed to have minimum surface area and maximum volume. The objective would be to provide storage and recreational facilities with reduced evaporation. From our experience with nuclear explosives, we know that we can create such lake basins.

Finally, the alteration of stream channels would involve the diversion of water from a river system whose flow is largely lost to sea into another river system which flows through an arid section, or into a closed basin.

VI. EARTHFILL DAMS

The possibility of using nuclear explosives as a tool in the construction of earthfill dams was suggested by the effects of the landslide associated with the recent (August 17, 1959) earthquake near Hebgen Reservoir in Montana. As a result of that slide, the Madison River was dammed and a large reservoir was formed behind. It would appear that nuclear explosives can also be used to construct similar dams. Before one can evaluate the feasibility of this idea, however, it will prove useful to examine the principles behind the construction of earthfill dams and some of the properties of Nature's own dams of this character.

Earthfill dams have been made for many years. Much is known about their cost, construction, stability, and general usefulness. A proper earthfill dam must have the following features:

1. It must be structurally sound;
2. It must have a firm foundation;
3. It must have a spillway to take care of floods; and
4. Leakage through it must be small and controlled.

In addition, most such dams have power plants or irrigation canals, along with the necessary penstocks and tunnels for control.

Normal civil engineering practices will guarantee structural strength. In order to minimize the leakage through an earthfill dam, the dam is built with a core of material effectively impermeable to water. The downstream portion is designed to control seepage through and under the dam. To reduce the probability of dam failure because of a foundation leak, excessive uplift pressure, or slippage, surface material is normally removed until a stable, solid foundation is reached. The earth fill and the impermeable core are then tied into the foundation in a manner designed to provide both a high structural strength and a good water seal.

The spillway is one of the most important features of an earthfill dam. If it is not designed properly, it may be eroded by the action of waters passing over it, usually resulting in the failure of the dam itself. In general, spillways should not be built on top of the earth fill, as subsidence of the dam proper may cause cracking and disruption of the spillway surface. Good engineering practice suggests that the spillway be built in solid rock alongside the earth fill, if possible, or, preferably, at some distance from it. Intakes, penstocks, and power plants must be constructed in or on stable material with sound foundations; they are often placed underground or at the sides of the dam.

Several naturally-occurring earthfill dams have been studied by the Laboratory staff and its consultants. Some of these were made by the gradual slippage of material over a lubricating layer of matter, such as moist clay. Others, like the one near Hebgen, are the result of landslides triggered by earthquakes. In most cases, no attempt was ever made to modify the dam; the dams eventually failed, either because they were undermined by leaking water or because, in the absence of a spillway, water flowing over the top of the dam eroded it away. There are, however, several cases of fairly long dam life before giving way. For example, the Gros Ventre slide dam, made in 1925 near Jackson Hole, Wyoming, formed a lake 180 feet deep which lasted two years before the failure of the top of the dam. The lower part of the dam held, and hence a sizable lake still exists there. If the dam had been made impermeable by proper treatment and if a good spillway had been constructed, it is quite likely that the dam would have survived.

The landslide near Hebgen carried about forty million cubic yards of rock into the valley and formed a dam along the river about 3,000 to 4,000 feet from toe to heel. The dam, which does not leak significantly, was high

enough to create a lake 200 feet deep, containing about 100,000 acre feet of water. In order to prevent failure of the dam and consequent flooding of downstream areas, the Army Corps of Engineers, under Lt. Col. Walter Hogrefe, working with a group of contractors, constructed a spillway on top of the dam. This procedure involved lowering the top of the dam about 60 feet in order to reduce the gradient of the spillway sufficiently to minimize erosion. As a result, the depth of the lake was reduced to 140 feet and the amount of water impounded to 35,000 acre feet. On a recent inspection of the dam, Col. Hogrefe said that the spillway seemed to have eroded very little since its completion last October and that he expected it to stand up for a long time, unless a very heavy river flow occurs.

The dam, as it exists today, is a moderately good earthfill dam in spite of the fact that it was not planned. If it had had a prepared foundation and if a water utilization and control system (intakes, penstocks, spillway, and power plant) had been built beforehand, it could have been a multipurpose dam. It must be recognized, incidentally, that there is nothing unusual about the origin of this dam. It could have been made in a number of geological settings; its only novel feature is that, by the addition of a spillway, it has been converted into a reasonably permanent structure. The lake formed by this dam will probably be used as a recreation area beginning next year. The danger of flooding is now small, and this dam will serve at least one useful purpose.

In the proper geologic environment, an underground nuclear explosion could create an earthfill dam. One possibility is to bury the nuclear explosive underground part way up one side of the valley to produce an artificial earthquake and, thereby, to trigger a landslide. Another idea, and probably a more useful one, was suggested by our experience in Nevada. Neptune, an

underground explosion mentioned earlier, produced a large crater on a 30° slope. Most of the material ejected from the crater was thrown down the slope. If we use the scaling laws appropriate to nuclear explosions in tuff, we find that a 300-kt nuclear explosion would transport, under conditions analogous to those of Neptune, 40 million cubic yards of rock downslope. In a valley like that of the Madison River, the dam would have dimensions comparable to those of the new dam. It would be extremely stable, as its thickness from toe to heel is more than four times that required for a man-made earthfill dam of the same height. Proper choice of materials and subsequent treatment should make the dam impermeable. In the course of this treatment it would be essential to be able to control the flow of river water as the lake fills up behind the dam. For this reason it would be desirable to build the foundation and the water utilization system in advance. Such a foundation should be stable, and good design would control leakage around the edges of the dam. An intake and penstock built into the mountainside across the valley from the crater can be engineered to survive the explosion, inasmuch as the tunnel leading to Blanca, a 20-kt underground explosion at the Nevada Test Site, was undamaged at a distance of 1,000 feet from the shot point (except for some movement along pre-existing fault planes at greater distances). The spillway should be built into the side of the mountain, or, better, constructed in another saddle leading out of the valley. A spillway over the top of the dam should be avoided.

It would appear from the discussion in Section III above that the radioactive debris would not constitute a serious problem. As we do not, at the present time, foresee any insuperable difficulties, we believe that, in a favorable geologic environment, an underground nuclear explosion can be used to

create an earthfill dam. Where appropriate, the technique should be examined as a possible competitor to conventional methods of dam construction using earth fills.

VII. SALINE WATER CONVERSION

The technical problems associated with the desalinization of sea water with the aid of nuclear explosives appear to be quite difficult. Nevertheless, the potential value of such a technique is great enough to justify a brief description of the basic idea.

When sea water is distilled at very high pressures and temperatures, salt-free water can be produced with a minimum of expended energy. These two conditions, high pressure and temperature, along with an inexpensive source of energy, are created when a nuclear explosive is fired and the underground cavity persists after the explosion. The high temperature would be maintained by the insulating properties of the earth and the high pressure by the effects of gravity.

Conceptually, sea water would be led several thousand feet down a pipe into a cavity which has been heated by the detonation of a nuclear explosive. Salt would be deposited and salt-free water returned to the surface through heat exchangers.

While this application is a potentially important possibility, its value cannot be assessed until further information on the phenomenology is obtained. It is hoped that the Gnome experiment, a nuclear explosion which will be detonated in the Salado salt formation near Carlsbad, New Mexico, will shed some light on this problem.

48186 O—60—pt. 23——3

VIII. SOVIET EXPERIENCE WITH LARGE EXPLOSIONS

Scientists in the Soviet Union have been looking into large explosions for construction purposes for a number of years (see Appendix IV). In December, 1957, they detonated a highly instrumented charge of 1,000 tons of chemical explosives near Tashkent. The experiment was for scientific purposes, in order to acquire data for application to "the construction of canals, ditches, trenches, and reservoirs." The crater formed in the explosion is now in use as a deep reservoir holding about 150 million gallons of water.

A few months later the Russians exploded the third in a series of large chemical charges to construct a diversion canal. A high explosive charge of 3,100 tons was detonated at one time to change the route of the Kolonga River (near Sverdlovsk) in order to make accessible a large deposit of iron ore. Their future plans include a 30,000-ton project (presumably using high explosives) to widen the Angara River bed in Siberia. In addition, a number of dam and river projects (see Appendix V) have been proposed during the current seven-year plan (1959-1965).

It is evident, then, that the Soviets have made significant progress toward the understanding of large subsurface explosions (and hence of underground nuclear explosions) and their application to peaceful projects. It is equally evident that their future programs are even more ambitious than those they have already executed. The detailed results of their experiments have not yet been made available to us, and, in view of the present international situation, they are not likely to become available in the near future. The Russians have, therefore, a definite lead in this aspect of the scientific application of nuclear explosives for peaceful purposes.

IX. PRESENT KNOWLEDGE OF EXPLOSION PHENOMENOLOGY

We believe that we understand, to some extent, the interactions of a nuclear explosive with Oak Springs tuff, in which a number of nuclear detonations have already taken place, but we do not know to what extent the phenomenology will be different in other geologic environments. We certainly need data in different media. Specifically, experiments would be extremely desirable in:

1. A drier, more competent rock (e.g., granite);
2. A wet, weakly-cemented material (e.g., alluvium);
3. A common aquifer material (e.g., sandstone);
4. An easily decomposable substance (e.g., limestone); and
5. A plastic medium (e.g., salt).

In all of these media, one can expect the ranges of the various effects of the explosion to be different from those we have seen in tuff; one can also anticipate that the geologic structure will exercise some influence on the observed phenomena. Some familiar processes may be absent (e.g., there may be no chimney) or some unexpected, new phenomena may be discovered. For this reason, it is vital that we gather fundamental data on the detailed interactions of nuclear explosives with other media whenever new nuclear tests (or large chemical explosions, for that matter) may be held, and for whatever objective they may be conducted. A program for this purpose involves both instrumental investigations during the explosion phase and post-shot digging and drilling to examine the ultimate condition of the medium.

Once we have appropriate data in another kind of rock, we will be able better to evaluate our calculational methods and to check the validity of our theoretical picture of the interactions of nuclear devices with various media.

We will also be able to predict, with a greater degree of reliability, what will happen if a nuclear device is detonated at a specific site in a particular medium. Without this ability we will be severely handicapped in the development of peaceful uses of nuclear explosions.

X. COSTS AND CONCLUSIONS

The ultimate test of a new technique for construction or development is, of course, its economic and engineering feasibility. Not only must a proposed project be technically sound, but the total costs involved must be competitive with those of other methods of achieving the same or similar objectives. In the case of a new, untested technique, there must be considerable savings accruing (in the form of time, money, permanence, or accomplishment) from the use of a novel approach before an industrial concern or a governmental agency will forego the comfort of more conventional methods of construction. While the earliest projects using nuclear explosives may not have to meet these severe economic criteria (as the development cost of experimentation with a new technique can be amortized over a number of subsequent applications), the use of nuclear explosives must show promise of significant superiority for some purpose before one will be willing to undertake the expensive empirical studies required to learn precisely how to apply the technique.

According to figures released by the U. S. Atomic Energy Commission, a nuclear explosive in the range of a few kilotons or a few tens of kilotons of energy yield can be provided for about $500,000. For this price the AEC will supply the explosive and detonate it, and will be responsible for the radiological protection of the public. The user will be expected to furnish a cased emplacement hole of appropriate depth. When everything is taken into account, the cost of exploding a 10-kt nuclear explosive at a depth of 1,200 feet would be of the order of one million dollars.

In discussing projects of this nature it is important to recognize several facts. First of all, no proposal for the use of nuclear explosives on a small scale can possibly compete with conventional methods. Secondly, the cost of a nuclear project increases quite slowly with the energy release, and hence

the economics of the nuclear technique becomes rapidly more favorable as the size of the required explosive increases. Indeed, if a megaton explosion should be appropriate, the explosive could be supplied, emplaced, and detonated for $1,000,000, only twice the fee for a 10-kt explosive. A larger hole would be needed, of course, and the required depth of burial of the explosive would be greater, but the cost of the associated construction would be multiplied by a factor far smaller than the 100-fold increase in the size of the resultant nuclear explosion. Thirdly, most of the possibilities for the use of nuclear explosives in water resource development are in the nature of capital improvements. The immediate gains may not be striking, but the sum total of significant annual benefits over the long life of the development can be large.

In summary, then, we at the Lawrence Radiation Laboratory believe that there are ways in which nuclear explosives can be used to assist in the development of the nation's water resources. Some of these may prove economical. However, we need the help of experts on water resources in developing actual projects. Our function is to provide technical information about the tool – nuclear explosives – and to analyze, evaluate, and predict its effects. We submit this note in the hope that the people and the organizations responsible for our country's water development will utilize this potent new technique.

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UNDERGROUND NUCLEAR DETONATIONS*

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Summary

Since 1952 eight nuclear explosions have been fired underground at the Atomic Energy Commission's Nevada Test Site. The explosions have varied in energy release from 55 tons to 19,000 tons of TNT equivalent and were carried out at depths varying from shallow burial to produce cratering to those depths at which no visible effects appeared on the surface. The major experimental data from these explosions, as well as the phenomenology of the deeper shots, is summarized here.

1. Introduction

During the 1955 nuclear weapons test series in Nevada it became increasingly clear to the Lawrence Radiation Laboratory that concern over fallout would be a serious limitation on future weapons tests. Therefore, based on a suggestion of Griggs and Teller [1956], consideration was given to the possibility of testing underground at such depths that there would be no escape of radioactivity to the atmosphere. Further detailed consideration led to the design of an experiment, code-named Rainier, to test the feasibility of containment of the radioactive debris from a nuclear explosion. This experiment conducted on September 19, 1957 was completely successful and all objectives of the experiment were achieved. The results of this 1.7-kiloton detonation have been previously reported in considerable detail [Johnson and others 1958, Johnson and Violet 1958, Diment and others 1959]. Its continued study has led to a fairly complete understanding of the physical and chemical processes associated with underground nuclear explosions. Subsequent to the Rainier detonation, five additional nuclear devices were fired underground at the Nevada Test Site during October 1958 in connection with

* Work was performed under the auspices of the U.S. Atomic Energy Commission.

weapon development programs. The preliminary results of these later explosions have been published [Johnson and Violet 1958].

In this paper all major results presently available from these shots, as well as three earlier cratering shots, are summarized and the phenomenology of these events is discussed.

2. Experimental Conditions

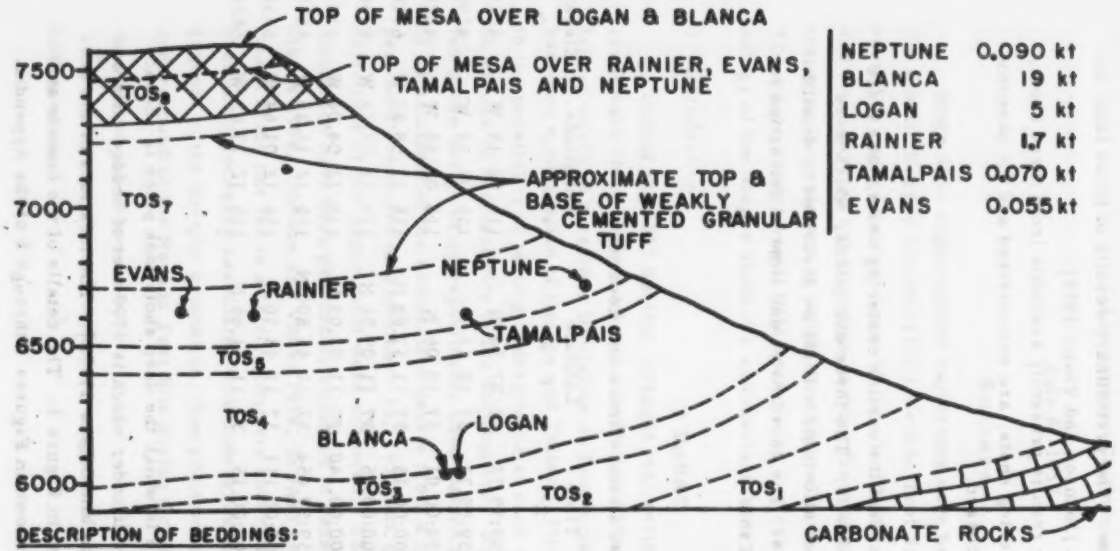
All of the explosions, except the earlier cratering shots, took place in a thick formation of bedded tuffs. The three exceptions, which were detonated in a lightly cemented alluvium, will not be described in detail but are included for completeness. The coordinates and time of detonation for each explosion are listed in Table 1.

TABLE 1

List of Events, Dates, Times and Locations

Event	Date	Time Z	Latitude ° ' "	Longitude ° ' "	Elevation ft
Jangle-S	19 Nov. 51	1659:59.72	37 07 54 N	116 02 19 W	4214
Jangle-U	29 Nov. 51	1959:59.72	37 10 11 N	116 02 33 W	4298
Teapot-Ess	23 Mar. 55	2030:00.01	37 10 06 N	116 02 38 W	4226
Neptune	14 Oct. 58	1800:00.15	37 11 37.88 N	116 11 58.88 W	6716
Blanca	30 Oct. 58	1500:00.15	37 11 09.36 N	116 12 07.28 W	6138
Logan	16 Oct. 58	0600:00.140	37 11 03.03 N	116 12 04.04 W	6141
Rainier	19 Sept. 57	1659:59.454	37 11 44.800 N	116 12 11.35 W	6615
Tamalpais	8 Oct. 58	2200:00.131	37 11 43.10 N	116 12 01.64 W	6616
Evans	29 Oct. 58	0000:00.15	37 11 41.46 N	116 12 17.03 W	6620

The geological structure in which the deep shots took place is characterized by 250 feet of welded tuff under which is 1700 feet of bedded tuffs and a thick bed of dolomite [Diment and others 1958a]. The locations of the several shot points are illustrated in Figure 1. The details of the tunnels and stemming for each event are shown in Figures 1 through 8 of the Appendix. A stratigraphic feature of some importance in interpretation is the loosely consolidated zone in Tos_7, the limits of which are indicated by dashed lines



DESCRIPTION OF BEDDINGS:

TOS_8 WELDED TUFF; RHYOLITE TO QUARTZ LATITE.

TOS_7 FRIABLE TUFF; MOSTLY ALL TUFFS ARE LOOSELY CEMENTED AND "SANDED"; LIGHT GRAY TO GRAYISH BROWN.

TOS_6 BEDDED TUFF; WELL CEMENTED; LIGHT YELLOW GREEN.

TOS_4 BEDDED TUFF; WELL CEMENTED, LIGHT GRAY TO BUFF, SOME PINK.

TOS_3 BEDDED TUFF; WELL CEMENTED, RED AT TOP AND BASE, PINK TO BUFF INTERBEDS.

TOS_2 BEDDED TUFF; MOSTLY LIGHT GRAY TO BUFF.

TOS_1 BEDDED TUFF; PURPLISH TO PINKISH RED.

MUL-7144

GENERAL NOTE:

1. THE DISTANCE RELATIONSHIPS BETWEEN THE ZERO W.P.'s AND THE PROFILE OF THE MESA, ARE CORRECT; HOWEVER, DUE TO THE COMPOSITE NATURE OF THE PROFILE, THE PROJECTED RELATIVE DISTANCES BETWEEN THE W.P.'s ARE NOT CORRECT.

Fig. 1. Profile of mesa showing zero sites.

in Figure 1. Rainier, Evans, Tamalpais, and Neptune were detonated in this lithologic unit about 100 feet below this lower limit. Blanca and Logan were detonated in Tos_3 about 600 feet below this limit.

Physical and chemical properties of the medium, averaged in the vicinity of the Logan, Blanca, and Rainier detonation points are listed in Tables 2 through 7.

TABLE 2

Average Values of Density, Porosity and Water Content
(Errors are standard deviations)

	Logan [Diment and others 1958b]	Blanca [USGS 1958]	Rainier [Diment and others 1959]
Dry bulk density (g/cm^3)	1.8±0.3	1.6±0.2	1.7±0.2
Natural state bulk density (g/cm^3)	2.1±0.2	1.9±0.2	2.0±0.2
Grain density (g/cm^3)	2.6±0.1	2.4±0.1	2.3±0.2
Porosity (percent)	30.6±7.4	33.2±6.0	24.4±7.0
Water content (weight percent)	14.5±3.5	17.5±3.5	15.3±3.5

TABLE 3

Average Chemical Composition
(Percent by weight for air-dry samples)

	Location	
	Logan [Diment and others 1958b]	Rainier [Diment and others 1959]
SiO_2	71.5	66.9
Al_2O_3	13.0	12.3
CaO	0.7	2.3
Fe_2O_3	1.8	2.2
MgO	0.4	1.0
Na_2O	1.3	1.3
K_2O	6.6	2.2
H_2O	4.5	10.6
Balance	0.2	1.2

Fig. 1. Profile of mesa showing zero sites.

TABLE 4

Mineral Composition by Volume Percent

	Logan and Blanca [USGS 1958]	Rainier [Diment and others 1959]
Phenocrysts	19.4	17.4
Quartz	6.9	2.6
Alkali Feldspar	5.6	6.1
Plagioclase	6.0	6.8
Biotite	0.5	1.3
Pyroxene and Amphibole	---	0.2
Magnetite	0.4	0.4
Xenoliths	1.6	6.7
Shards and Lapilli Matrix	70.7	68.4
Heulandite	not differentiated	23
Montmorillomite	"	12
β - Cristobalite	"	11
Amorphous Material	"	22
Vesicles	8.3	7.5

TABLE 5

Thermal Properties

A. Specific Heat* for Rainier Tuff (cal/gram/°C) [Warner and Violet 1959]

Water content, (grams H_2O/ gram dry sample)	Temperature °C: 25	100	200	400	600
0	0.18	0.21	0.24	0.27	0.30
0.15	0.28	0.31	-	-	-
0.20	0.31	0.33	-	-	-
0.30	0.34	0.36	-	-	-

*Calculated from chemical analysis. Does not include heat of vaporization of water.

(continued)

TABLE 5 (continued)

B. Thermal Conductivity ($cal/cm^2/sec/°C/cm$) [Diment and others 1958a]

	Rainier	Logan
Dry	0.0011	0.0014
Wet	0.0016	0.0020

C. Melting Range: 850-1500°C

D. Estimated enthalpy to molten state (≈1500°C): 700 cal/g
Estimated enthalpy to vapor state (≈3000°C): 3000 cal/g

TABLE 6

Average Values of Strength and Elastic Properties

A. Static Tensile Properties of Rainier Tuff [Diment and others 1959]

Air Dry Tensile Strength, psi	165
Air Dry Young's Modulus, psi	0.46×10^6
Air Dry Poisson's Ratio	0.12
Calculated Rigidity Modulus, psi	0.22×10^6

B. Static Compressive Properties of Rainier Tuff [Diment and others 1959]

	Air dry	Natural state	Natural state under hydrostatic pressure 1,000 psi
Compressive Strength, psi	4700	1200	5100
Young's Modulus, psi	1.1×10^6	0.18×10^6	0.37×10^6
Poisson's Ratio	0.11		
Calculated Rigidity Modulus, psi	0.50×10^6		

C. Dynamic Properties of Rainier Tuff [Diment and others 1958a]

f_L	f_T	b	v_L	v_T	$E\times10^6$	$G\times10^6$	σ
5900	4000	0.1	7940	5380	1.07	0.49	0.09

where f is resonant frequency, cps.

L and T are longitudinal and torsional modes, respectively.

b is specific damping capacity determined from width of resonance amplitude curve.

(continued)

TABLE 6 (continued)

v is calculated acoustic velocity, ft/sec.

E is calculated Young's modulus, psi.

G is calculated rigidity modulus, psi.

σ is calculated Poisson's ratio.

D. Bulk Modulus of Rainier Tuff, psi [Warner and Violet 1959]

	Unjacketed	Jacketed
Sample water-saturated	5.7×10^6	0.54×10^6
Average oven-dry sample	4.8×10^6	0.41×10^6

TABLE 7

Miscellaneous Properties of Rainier Tuff

A. Porosity at elevated pressures (average of 2 samples of 28% porosity) [Warner and Violet 1959]

Pressure, psi	0	1000	2000	3000	4000
% Reduction in porosity	0	6%	8%	10%	12%

B. Permeability to Air (millidarcies)[Warner and Violet 1959] to Brine (millidarcies

	Average*	Range**	Average	Range
Rainier	6.0	0.95 - 41	1.4	0.084 - 27
Logan	0.81	0.14 - 2.4	0.036	0.00076 - 0.24

*Averages are computed assuming log-normal distribution.

**Ranges are the total ranges of values observed.

(continued)

TABLE 7 (continued)

C. Seismic Velocity, Vertical Distribution over Rainier [Swift and Sachs 1959]

Interval depth below surface, feet	Interval velocity, ft/sec	Distance above Rainier shot room, feet
230 - 270	7,150	665 - 625
270 - 310	13,700	625 - 585
310 - 395	6,650	585 - 500
395 - 525	7,070	500 - 370
525 - 675	7,180	370 - 220
675 - 775	5,850	220 - 120

(Shot room at depth 895 feet.)

3. General Results

The gross results of the explosions will be described in terms of the visible behavior in the vicinity of the shot point, the escape of radioactivity, the air blast, and the ground shock. The explosions are listed in order of increasing scaled depth in Table 8. The scaled depth is defined as $D/W^{1/3}$, where D is the actual depth in feet and W is the energy release in kilotons (kt) of TNT equivalent. The depth D in the table is the distance to the nearest point on the surface. The column in the table entitled "Measured radioactivity deposited on surface" represents the percentages of the total radioactivity which appeared on the surface, neglecting possible enrichment of particular isotopes.

One kiloton of TNT equivalent is defined as the prompt release of 10^{12} calories of energy (4.2×10^{19} ergs). This energy is determined by multiplying the number of fissions, as measured radiochemically, by the prompt energy release (179 Mev or 2.86×10^{4} ergs per fission). Prompt energy is the sum of the kinetic energy of the fission fragments, and the prompt neutron and prompt gamma ray energies. The delayed energy release due to radioactivity decay amounts to another 22 Mev per fission. About 15 Mev of this energy appears eventually as heat, of which about 7 Mev is released in the first 20 minutes.

TABLE 8

Major Features of Underground Nuclear Explosives

Event	Yield (W) kt	Medium	Depth (D) feet	Scaled Depth $D/W^{1/3}$	Measured radioactivity deposited on surface %	Crater volume yd^3	Crater volume/kt yd^3
Jangle-S	1.2±0.1	Alluvium	-3.5*	-3.3*	>65	1,650	1,400
Jangle-U	1.2±0.1	"	17	16	>80	37,000	31,000
Teapot-Ess	1.2±0.1	"	67	63	90	96,000	80,000
Neptune	0.090±.020	Bedded Tuff	99	220	1-2	33,000	370,000**
Blanca	19.0±1.5	" "	835	310	<0.5	0	0
Logan	$5.0^{+0.2}_{-0.4}$	" "	830	485	0	0	0
Rainier	1.7±0.1	" "	790	670	0	0	0
Tamalpais	0.072±.010	" "	330	780	0+	0	0
Evans	0.055±.030	" "	840	2200	0++	0	0

*3.5 feet above surface.

**This explosion took place in bedded tuff under a sloping surface 1:3 so the crater is probably larger than would be expected on a level surface.

+No breakthrough to surface but radioactive gases in large quantities leaked into the tunnel.

++No breakthrough to surface but stemming failed, releasing gross fission activity into the tunnel.

A. Escape of Radioactivity

In discussing the effectiveness of containment of radioactivity it is necessary to examine not only the escape through the surrounding formation but also the success of the stemming in the tunnels.

For Rainier (1.7 kt) and Logan (5.0 kt) there was no detectable escape of radioactivity to the atmosphere or into the tunnels. From Blanca (19 kt) a chimney developed to the surface and broke out 15 seconds after the detonation. The cloud rose about 1,000 feet and deposited radioactivity on the ground. On integration of the radioactivity in the surveyed area (Figure 9, Appendix) it was found that 0.3 to 0.5% of the gross radioactivity escaped and had been deposited locally. Volatile isotopes were enriched several fold in the vented radioactivity.

The tunnels collapsed at radii of 200 feet (Rainier), 820 feet (Logan), and 850 feet (Blanca) from their respective centers of detonation. There was no detectable leak of radioactivity into the tunnels from any of these explosions. On digging back into the sites it was found that radioactivity had been projected down the tunnels 600 feet for Blanca and 190 feet for Logan.

From this experience it has been demonstrated that the radioactivity released by nuclear explosions can be successfully contained underground. It may be seen from Table 8 that the escape of radioactivity is small at a scaled depth of 300 $W^{1/3}$, and at a scaled depth of 500 $W^{1/3}$ it was not detectable. All radioactivity would probably be contained at a depth of 400 $W^{1/3}$ or greater in tuff.

Neptune, Teapot-Ess, Jangle-U, and Jangle-S, all produced craters and released radioactivity to the atmosphere. In all these cases almost all of the radioactivity that escaped returned to earth within a few miles. With Neptune (Figure 10, Appendix) only 1% of the radioactivity escaped and was deposited near the crater, although the volatile isotopes and those isotopes with gaseous precursors were enriched several fold as noted for Blanca.

B. Local Effects

The ground motion from Rainier was barely felt at 2.5 miles and that from Blanca at 16 miles. There was no structural damage to tunnels or to facilities at or beyond 2500 feet from Blanca. These facilities included a major electronic recording station and a ventilation blower system for the tunnel. These observations give a rough indication of damage radii.

The airblast effects for all shots at scaled depths of 200 $W^{1/3}$ or greater were negligible. These explosions were not audible at a distance of 2.5 miles, although some individuals reported hearing a dull boom from Rainier. While the explosions were not heard by ear, signals were detected by microbarographs in several locations [private communication, Jack W. Reed, Sandia Corp., 1958].

The details of fracturing and bedding plane shifts were mapped and have been described elsewhere [Diment and others 1959]. For Blanca a major section of the top of the mesa shifted down the slope forming a scarp about 70 feet high. The change in profile and area of slumping are shown in Figures 11 and 12 of the Appendix.

C. Earth Motion Measurements

Acceleration and displacement measurements on Rainier by the Stanford Research Institute [Swift and Sachs 1959], Edgerton, Germeshausen and Grier, Inc. [1958] and Sandia Corporation [Perret 1958], indicated that a large earth cap beginning approximately 180 feet below the mesa surface separated from the mesa over the charge and subsequently fell back into place. The only significant vertical displacement occurred at or near surface zero and reached a maximum of 1 foot. The peak acceleration at surface zero was 6 g at 186 milliseconds after zero time.

For Blanca [Swift and others 1959, Morris and Schneiderhan 1959, Perret, to be published] the accelerations measured on the mesa surface show vertical maxima that are consistently larger than the horizontal. The mesa surface directly above the Blanca detonation point was displaced vertically approximately 30 inches in about 400 milliseconds.

Seismic signals from the Rainier event were detected at various stations in the continental U.S. and at distances up to 1000 miles [Diment and others 1959, Carder and others 1958]. Seismic signals were also detected (though barely resolved) at College Station in Fairbanks, Alaska at a distance of 2200 miles.

Seismic effects [Carder and others 1959] resulting from Blanca, Logan, Tamalpais and events of Hardtack Phase-II underground explosions were measured by strong-motion and teleseismic seismographs out to distances of nearly 100 miles. In addition, many temporary seismographs were operated by a number of organizations to distances of nearly 2400 miles, and routine seismographs were operated on a world-wide basis.

Preliminary results indicate that the seismic effects were consistent with empirical formulas developed from Rainier data, except that attenuation of surface waves beyond 200 kilometers may have been higher than the formula for that distance would indicate. Results obtained from the smaller shots require considerably more thought before appraisal. Preliminary seismic data on Logan, for example, indicate that the fraction of energy in the seismic waves is about twice as large as expected from the Rainier formulas.

4. Detailed Local Results

Of the underground explosions, the first one, Rainier, has been studied in most detail and provides most of the data from which a model has been developed. Radioactivity and temperature distributions were determined by drilling and logging a series of holes through the active region. Cores were also recovered and subjected to chemical, radiochemical, and physical property determinations. Similar work, although not in as much detail, has been accomplished for the other explosions. In addition to drilling, two drifts have been driven through the Rainier shot zone. One drift passed about 25 feet below and one about 100 feet above the center of detonation. The layout of drill holes and drifts is shown in Figure 2. Explorations by means of drill holes permitted the determination of the properties of the medium surrounding the center of the explosion.

A. Temperature Distribution

The temperature distribution [Goodale and others 1958, Olsen and others 1959] for Rainier measured five months after detonation is shown in Figure 3.

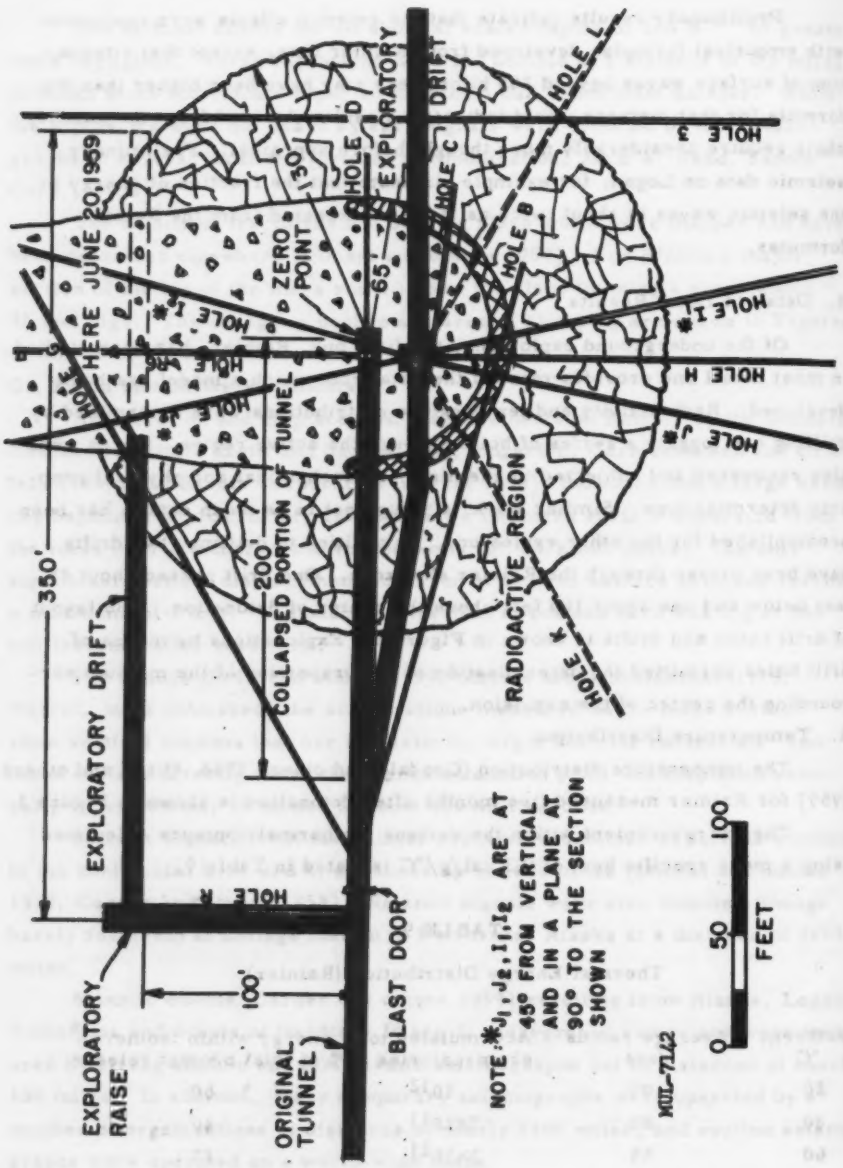
The energy-content within the various isothermal contours calculated using a mean specific heat of 0.3 cal/g/°C is listed in Table 9.

TABLE 9

Thermal Energy Distribution (Rainier)

Isotherm °C	Average radius feet	Accumulated total energy within isotherm* gram-calories	% of total prompt release
20	100	10^{12}	60
40	80	7×10^{11}	40
60	55	3×10^{11}	17
80	30	6×10^{10}	3

*The temperature distribution was assumed to be axially symmetric.


HOLE 3
HOLE L
HOLE D
EXPLORATORY DRIFT
HOLE C
HOLE B
HOLE I*
HOLE H
HOLE J*
HOLE K
HOLE A
HOLE R6
HOLE 1*
HOLE 4
HOLE 2
HOLE 5
HOLE 6
HOLE 7
HOLE 8
HOLE 9
HOLE 10
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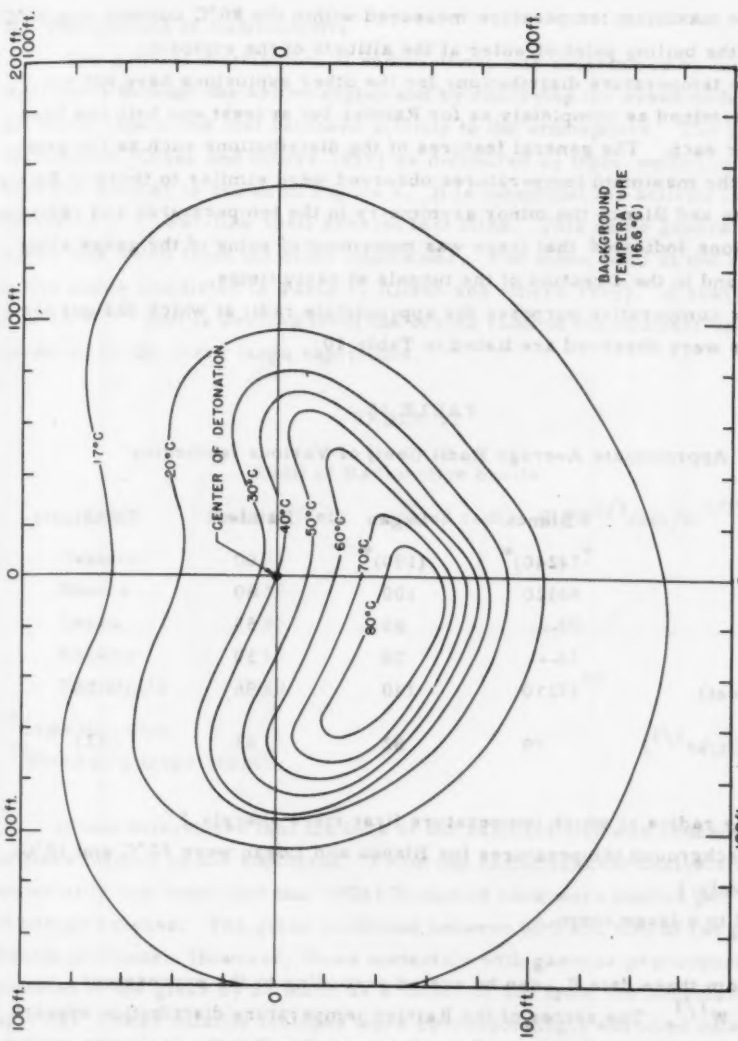


Fig. 3. Temperature distribution of Rainier, five months after detonation.

Fig. 2. Drifts and drill holes for post-shot studies of Rainier.

The maximum temperature measured within the 80°C contour was 94°C, which is the boiling point of water at the altitude of the explosion.

The temperature distributions for the other explosions have not yet been determined as completely as for Rainier but at least one hole has been logged for each. The general features of the distributions such as the geometry and the maximum temperatures observed were similar to those of Rainier. For Logan and Blanca the minor asymmetry in the temperatures and radiation distributions indicated that there was movement of some of the gases along fissures and in the direction of the tunnels at early times.

For comparative purposes the approximate radii at which various temperatures were observed are listed in Table 10.

TABLE 10

Approximate Average Radii (feet) of Various Isotherms

Isotherm °C	Blanca	Logan	Rainier	Tamalpais
20	(240)*	(190)*	100	---
40	120	100	80	---
60	---	80	55	---
80	---	70	30	---
R_T (feet)	210	140	96	50
$\frac{R_T}{W^{1/3}}$ (ft/kt$^{1/3}$)	79	82	81	121**

(R_T is the radius at which temperature first rises sharply.)

*(The background temperatures for Blanca and Logan were 20°C and 18°C, respectively.)

**Fired in a large room.

From these data R_T can be scaled according to the expression: $R_T = 81\ W^{1/3}$. The center of the Rainier temperature distribution appears to be displaced laterally about 20 ft. It is possible that the early gas venting took place in such a direction as to account for this effect. A large open vertical fault did exist 50 feet from that side of the point of detonation, but whether venting actually occurred into this region is not known.

B. Distribution of Radioactivity

The general distribution of radioactivity was determined by logging drill holes through the active region and by surveying the areas of fallout for those explosions that released activity to the atmosphere. The gross distribution [Olsen and others 1959] as measured by thick-walled ion chambers for Rainier is shown in Figure 4. It is noted that the activity is concentrated in a bowl-like shell several feet thick. This same general distribution was noted from the other explosions. The mean radii of the radioactive zones are listed in Table 11 [Olsen and others 1959]. A scaling law $R = 50\ W^{1/3}$ feet is derived from the scaled radii of the radioactive shells produced by the three large explosions.

TABLE 11

Radii of Radioactive Shells

Event	Radius (feet)	Scaled radius ($R/W^{1/3}$ feet/kt$^{1/3}$)
Neptune	21	47*
Blanca	130	48
Logan	85	50
Rainier	62	52
Tamalpais	30	73**

*Cratering shot
**Fired in a large room

It was determined that the bulk of the radioactivity was concentrated in glass formed by the explosion. From the radiochemical analysis of this material it was concluded that 500±150 tons of rock were melted per kiloton of energy release. The glass contained between 60% and 85% of the gross fission products. However, those materials with gaseous precursors were depleted in the glass by as much as a factor of 100 from the nonvolatile species. These volatile isotopes were correspondingly enriched outside the radioactive shells.

Since the fission products are comprised of many elements their volatilities range from very large (krypton, xenon) to very small (zirconium, cerium). The relative abundance of those species which are gaseous and refractory changes as radioactive decay processes proceed after the detonation.

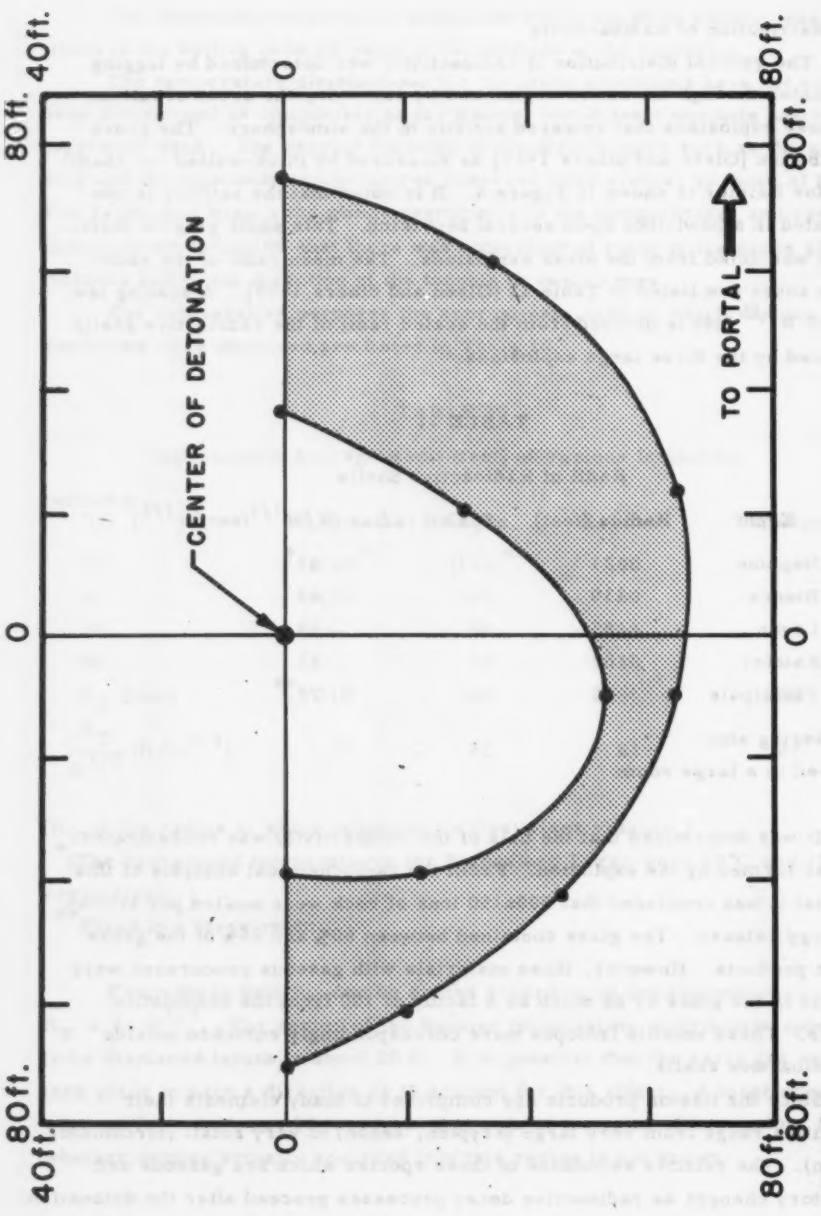


Fig. 4. Distribution of radioactivity — Rainier Event.

Table 12 is a list of the parent-daughter relationships leading to some of the isotopes which were later determined radiochemically.

TABLE 12

Decay Chains Leading to Isotopes Which Have Been Measured in Debris from Underground Explosions

Mass	Element, half-life and measured isotope (underlined)
85	As $\xrightarrow{0.43\ \text{sec}}$ Se $\xrightarrow{40\ \text{sec}}$ Br $\xrightarrow{30\ \text{min}}$ <u>Kr</u>
89	Kr $\xrightarrow{3.2\ \text{min}}$ Rb $\xrightarrow{1.5\ \text{min}}$ <u>Sr</u>
90	Kr $\xrightarrow{33\ \text{sec}}$ Rb $\xrightarrow{2.7\ \text{min}}$ <u>Sr</u>
91	Kr $\xrightarrow{9.8\ \text{sec}}$ Rb $\xrightarrow{2\ \text{min}}$ Sr $\xrightarrow{9.7\ \text{hour}}$ <u>Y</u>
95	Rb $\xrightarrow{\text{sh}}$ Sr $\xrightarrow{\text{sh}}$ Y $\xrightarrow{10\ \text{min}}$ <u>Zr</u>
99	Zr $\xrightarrow{30\ \text{sec}}$ Nb $\xrightarrow{2.5\ \text{min}}$ <u>Mo</u>
137	I $\xrightarrow{22\ \text{sec}}$ Xe $\xrightarrow{3.8\ \text{min}}$ <u>Cs</u>
140	Xe $\xrightarrow{16\ \text{sec}}$ Cs $\xrightarrow{66\ \text{sec}}$ <u>Ba</u>
141	Xe $\xrightarrow{1.7\ \text{sec}}$ Cs $\xrightarrow{\text{sh}^a}$ Ba $\xrightarrow{18\ \text{min}}$ La $\xrightarrow{3.7\ \text{hour}}$ <u>Ce</u>
144	Cs $\xrightarrow{\text{sh}^a}$ Ba $\xrightarrow{\text{sh}^a}$ La $\xrightarrow{\text{sh}}$ <u>Ce</u>

[a] sh – short (compared to a few seconds.)

The effect of the gaseous ancestors in leading to the depletion of certain nuclides from the glass and their enrichment in the vented material is demonstrated in Table 13. These data are the summarized radiochemical results from all of the explosions in tuff.

Fig. 4. Distribution of radioactivity – Rainier Event.

TABLE 13

Summary of Radiochemical Data from Several Underground Explosions

Isotopes*	Percentage of total in fused material	Degree of enrichment in rubble chimney	Degree of enrichment in vented material***
Kr^{85}	< 1%	~0	All in gas
Sr^{89}, As	3 - 10%	>2	~10
Sr^{90}, Cs^{137}	20 - 40%	>2	~5
Y^{91}, Ba^{140}, Ce^{141}, Cs	30 - 60%	>2	> 2
U, Mo^{99}	50 - 100%	< 2	< 2
Pu, A.E.**, Pa, Hf Ta, Ce^{144}, Nd^{147}	~100%	1.0	1.0

* Examples which have been measured.

** A.E. represents actinide earth.

*** Observed from Neptune and Blanca.

It should be noted that since Sr^{89} and Sr^{90} are strongly depleted in the glass debris, the gases must have escaped from the glass in times comparable to the half-lives of their krypton ancestors (3.2 minutes and 33 seconds). At the temperatures in the cavity, around 1000° or 1500°C, several other fission products are volatile and also appear to be depleted from the glass and enriched in the vented material. Arsenic, cesium, and uranium appear to behave in this way.

5. Phenomenology

The following discussion largely pertains to Rainier since most of the measurements have been completed at that site. Based on the fact that the radioactivity and temperature distributions were concentrated in shells and that within these shells the region was generally permeable to drill water, while outside it was much less permeable, led to the conclusion that the explosions produced cavities of radius $R = 50\ W^{1/3}$ feet, which stood for a short time, then collapsed.

In the case of Rainier, the description of the state of the cavity at this time and its collapse has been described by Kennedy and Higgins [1958]. The cavity when first formed was lined with about 4 inches of melted rock and filled with steam at a pressure of 40 atmospheres, which is approximately the lithostatic pressure. The cavity stood long enough, between 30 seconds and 2 minutes, for much of the fluid rock to flow down the sides and to drip from the roof. At this time the cavity began to collapse and cooled rapidly due to expansion of the steam. The sudden cooling quenched some of the droplets of rock in free fall, as well as some of the 'icicles' as they hung suspended from the cavity roof. The cavity was filled with broken rock from the collapse, and the caving progressed vertically to a distance of 386 feet above the point of detonation.

Inspection of the interior of the collapsed zone revealed the distribution of size of blocks formed. The blocks in the lower drift varied from a few inches in diameter, just inside the radioactive zone, up to several feet in diameter near the center. The regions between the blocks were filled with pulverized material which had resolidified by the time the re-entry was accomplished one year after the explosion. The recementing is not surprising for material with high clay content.

The drift, 100 feet above the zero point, first broke into a block-caved region 75 feet out from the vertical line passing through the center of detonation. At this point the blocks were a few inches to a few feet in diameter with open fractures, then graduated down to a fine powder at a distance of 65 feet. At a distance of 40 feet a large cavity was encountered. In summary the collapse of the initial cavity produced a broken permeable zone that appears to be cylindrical with a radius of 65-75 feet for the first 100 feet of height, and with a total height of about 386 feet. The radius of the collapsed zone above 100 feet has not yet been measured.

Soon after detonation the high temperature rocks rapidly cooled to the boiling point of water (94°C, at this altitude - 6600 feet), because of the water content of this tuff and the large permeable zone resulting from the collapse of the cavity. The diffusion of heat then took place at a lower rate leading to the observed distribution measured five months after detonation (Figure 3).

The Rainier device was detonated in a room 6'×6'×7', which contained about one ton of material. The initial temperature and pressure in the room can be calculated as follows:

$$\text{Energy density: } E = E_p + E_r = \frac{3}{2} n kt + \frac{4\sigma T^4}{c}$$

where E_p = energy density in the particles
E_r = energy density in radiation
$n = A_o\rho/M$ = number of particles per cm^3
$k = 1.37\times10^{-16}$ erg/°K (Boltzmann's constant)
T = Temperature °K
$\sigma = 5.74\times10^{-5}$ erg/cm^2/°K^4 (Stefan-Boltzmann constant)
$c = 3\times10^{10}$ cm/sec (velocity of light)
$A_o = 6.04\times10^{23}$ (Avogadro's number)
M = molecular weight
ρ = density in g/cm^3

This can be put in the form

$$E = 3/2\ \frac{A_o\rho}{M}\ kT + \frac{4\sigma T^4}{c}$$

$$= 1.25\times10^{8}\ \frac{\rho}{M}\ T + 7.65\times10^{-15}\ T^4 \quad \text{erg/cm}^3$$

The pressure equals 2/3 particle energy density plus 1/3 radiation energy density thus

$$P = 0.83\times10^{8}\ \frac{\rho}{M}\ T + 2.55\times10^{-15}\ T^4 \quad \text{dynes/cm}^2$$

The prompt energy release of the Rainier explosion was 7.2×10^{19} ergs Since the mass of material in the room was about 10^6 g and the volume was 7×10^6 cm^3, the mean density was 0.14 g/cm^3. At extremely high temperatures essentially all electrons are stripped from nuclei and since the atomic weight is approximately twice the atomic number, the effective molecular weight is given by

$$M_{eff} = \frac{\Sigma N_i \times 2\ Z_i}{\Sigma N_i\ (Z_i + 1)} \approx 2$$

where N_i is the number of atoms of atomic number Z_i and the summation is taken over all atoms in the zero room. Applying these numbers as indicated leads to the fact that the temperature a few microseconds after detonation was about 1,000,000°K and the pressure 7,000,000 atmospheres (bars). The radiation pressure at this temperature is 2500 bars.

The calculation of the behavior of the medium from this point onward was carried out by J. Nuckolls [1959], who extended the earlier calculations of Pelsor [private communication]. Nuckolls' treatment involved the development of a code for a computer calculation of the behavior of the medium

from a few microseconds to about 100 milliseconds. This time was sufficiently long to permit calculation of all the dynamic behavior of the system. Only the general results of this calculation will be given here.

It was assumed that tuff has negligible large-scale tensile strength and behaves as a linear elastic solid as long as the tension does not exceed the stress due to overburden pressure. The elastic constants used in the calculation were the measured values for bulk modulus, shear modulus, and sound speed. After the tension in the spherical shell exceeds the lithostatic stress the components of the stress tensor are set equal to a pressure (shear modulus equal to zero) which is related to the volume by a bulk modulus type equation of state.

From the calculations, the shock time-of-arrival was determined. This information together with the measured results of Porzel [Cohn and others, to be published] are shown in Figure 5. In Figure 6 the peak shock pressure as a function of radius is given. It decreases as $r^{-2.35}$ out to about ten meters. The tuff was vaporized to a radius of 2.3 meters in 0.2 milliseconds (peak pressure 1.0 megabar) and melted by shock to 3.3 meters (0.4 mb). Enough energy was deposited by the shock in the first 4.6 meters to melt all the tuff within this radius (660 tons). Radiochemical analysis on Rainier gave about 800 tons. This total amount melted is the sum of the shock induced melting (660 calculated) and the melting induced by fission-product decay energy and should be about 1.2 times larger than the shock induced melting alone. The factor 1.2 results from the ratio of the percentage of prompt energy in gas + liquid + fission product divided by the prompt energy in gas + liquid.

The shock progressed outward and crushed the medium to a radius of 130 feet where the pressure was 1.4 kilobars, or twice the static compressive strength. The elastic radius was calculated to be 285 feet horizontally and 305 feet vertically.

It was calculated that a spherical cavity was formed which expanded outward as the shock advanced. The melted tuff formed the inner surface of this cavity. The calculated rate of growth of the cavity is given in Figure 7. It is noted that it reached its maximum radius of 62 feet in about 80 milliseconds. The radius that was determined experimentally is in agreement with this value.

Nuckolls also calculated the energy and temperature distribution at 90 milliseconds after detonation. At this time, less than 0.5 percent of the energy is kinetic energy and therefore the system is essentially static (Table 14).

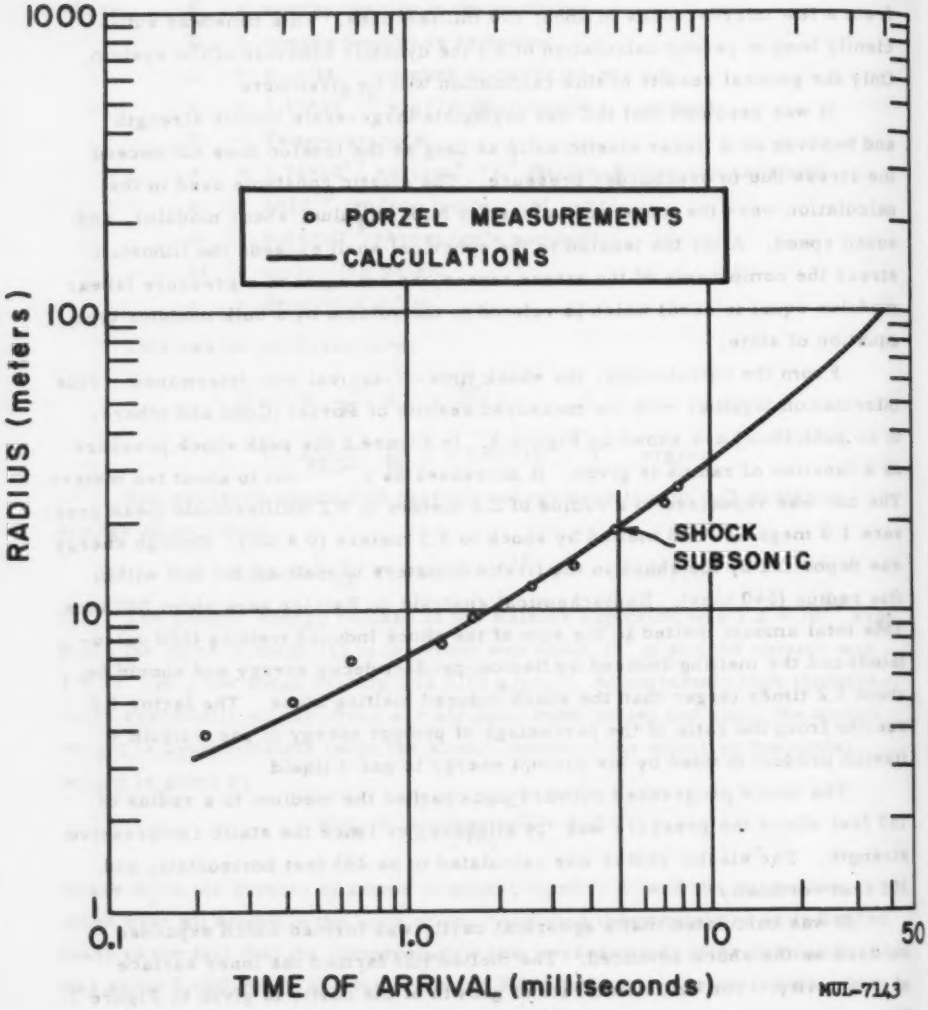


Fig. 5. Shock time-of-arrival – Rainier Event.

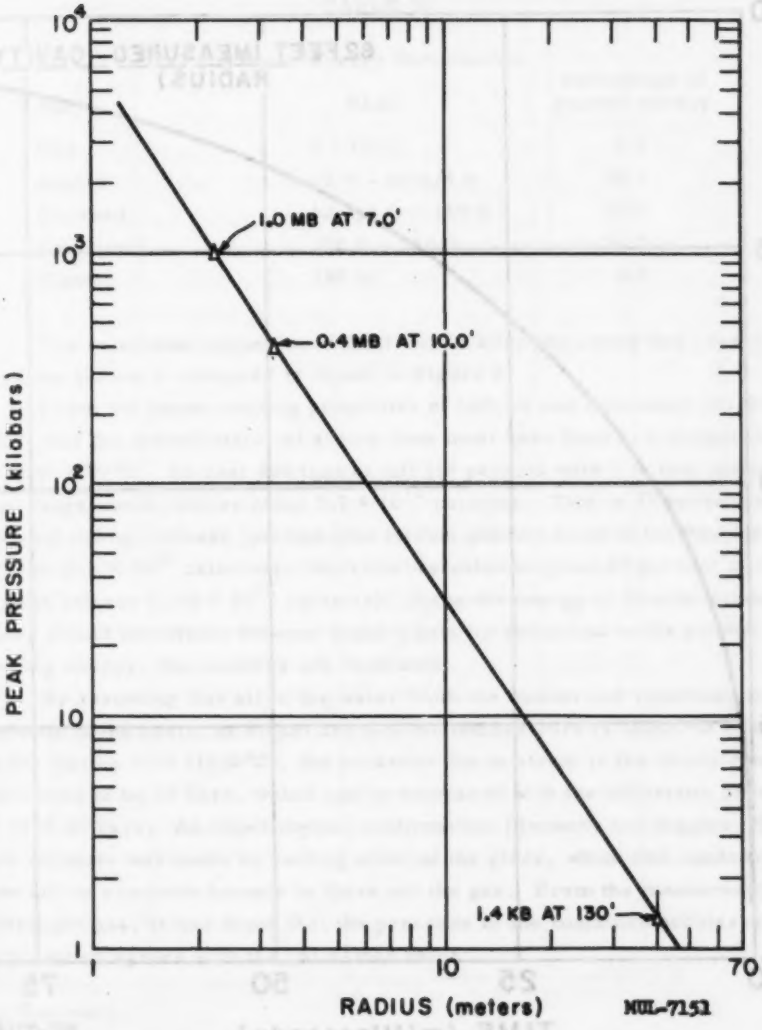


Fig. 6. Peak shock pressure – Rainier Event.

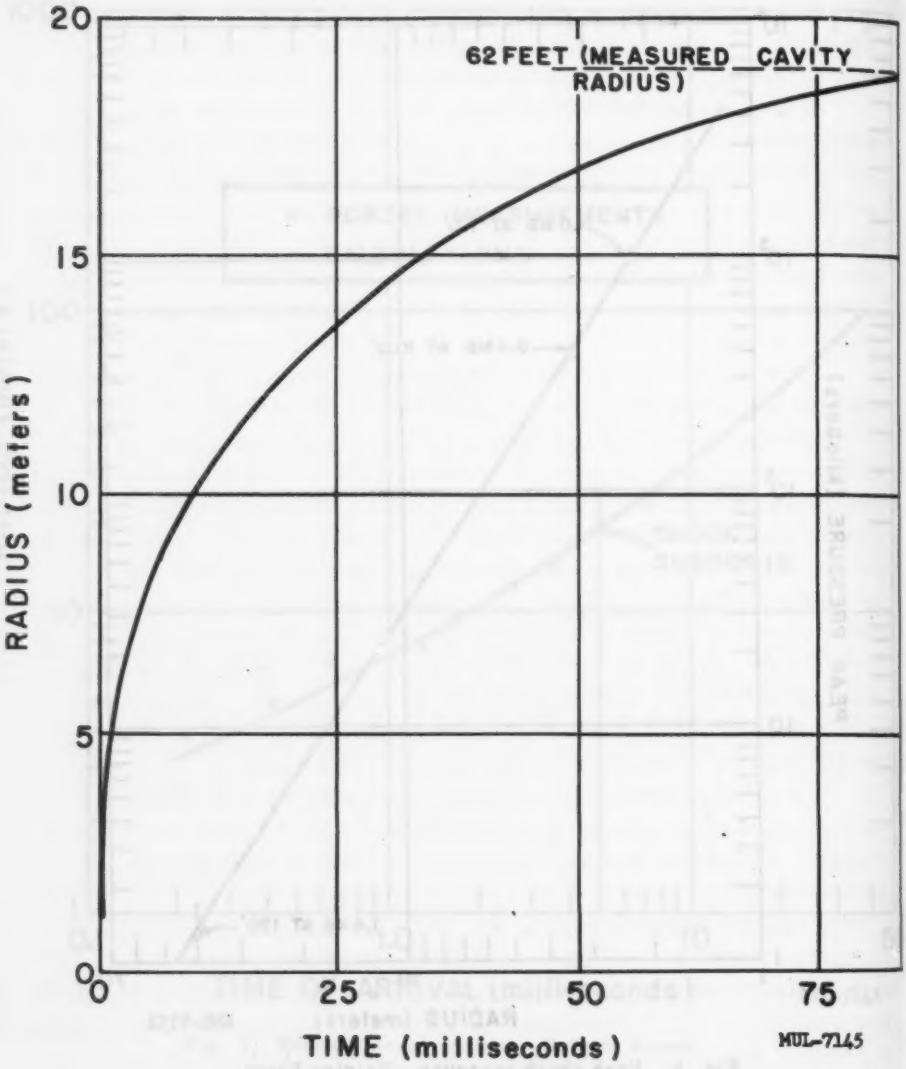


Fig. 7. Rate of growth of Rainier cavity.

TABLE 14

Rainier Energy Distribution

State	Radii	Percentage of prompt energy
Gas	0 - 62 ft	8.2
Liquid	62 ft - 62-1/4 ft	19.1
Crushed	62-1/4 ft - 130 ft	47.0
Fractured	130 ft - 280 ft	21.2
Elastic	280 ft	4.5

The calculated temperature distribution after the cavity had ceased to grow but before it collapsed is shown in Figure 8.

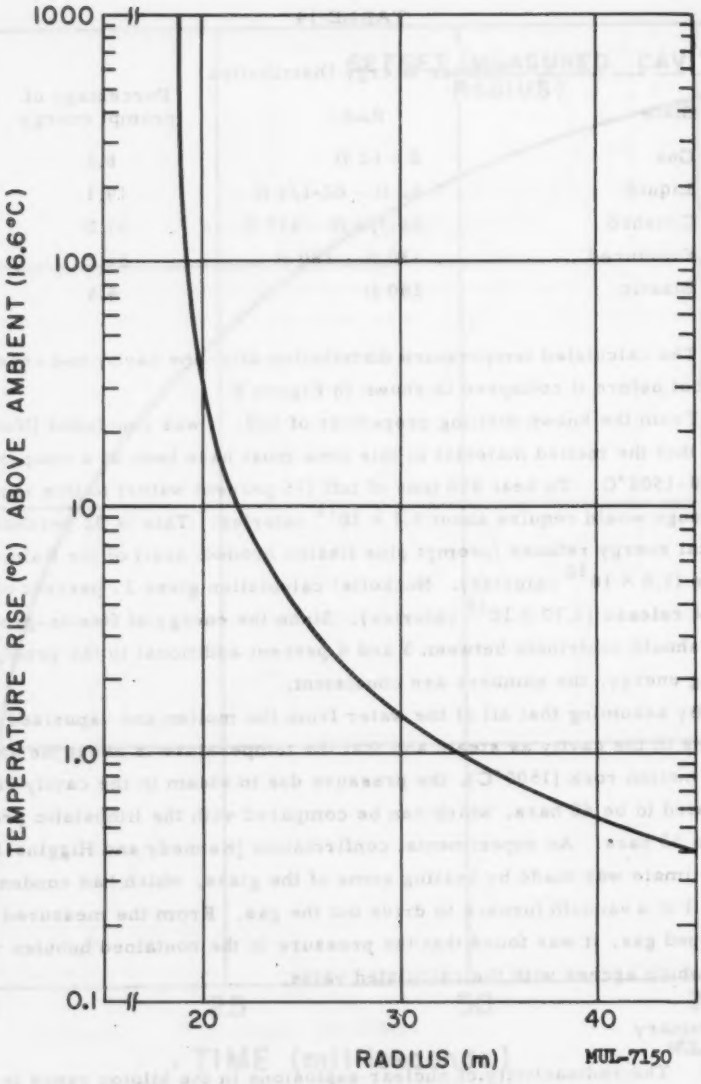
From the known melting properties of tuff, it was concluded [Nuckolls 1959] that the melted material at this time must have been at a temperature of 1200-1500°C. To heat 800 tons of tuff (15 percent water) to this temperature range would require about 5.7×10^{11} calories. This is 32 percent of the total energy release (prompt plus fission product heat) of the Rainier explosion (1.8×10^{12} calories). Nuckolls' calculation gives 27 percent of the prompt release (1.70×10^{12} calories). Since the energy of fission-product decay should contribute between 3 and 4 percent additional to the prompt melting energy, the numbers are consistent.

By assuming that all of the water from the molten and vaporized rock remains in the cavity as steam and that the temperature is about the same as the molten rock (1500°C), the pressure due to steam in the cavity can be calculated to be 40 bars, which can be compared with the lithostatic pressure of 50 to 55 bars. An experimental confirmation [Kennedy and Higgins 1958] of this estimate was made by heating some of the glass, which had condensed in free fall in a vacuum furnace to drive out the gas. From the measured quantity of trapped gas, it was found that the pressure in the contained bubbles was 40 bars, which agrees with the calculated value.

6. Summary

1. The radioactivity of nuclear explosions in the kiloton range in tuff can be completely contained underground at depths of $D = 400\ W^{1/3}$ feet or greater.

2. The initial cavity formed by the explosion has a radius of $R = 50\ W^{1/3}$ feet.



Fig, 8. Initial Rainier temperature distribution.

3. Initially melted rock, which is converted to glass on cooling, amounts to 500 ± 150 tons per kiloton of energy release.

4. The collapse of the cavity produces a zone of about 70,000 yds^3/kt (120,000 tons/kt) of broken permeable material.

5. The major portion (65-80 percent) of the gross fission product activity is in dilute (one part per 10,000,000) solution in glass. The remainder (20-35 percent) is distributed throughout the collapsed zone of the chimney and is deposited on the surface of the broken material.

6. About 30 percent of the total energy release of the explosion is initially deposited in steam and hot rock at a temperature in excess of 1200°C. This temperature rapidly degrades to the boiling point of water. One year after the Rainier explosion this energy resided within a volume whose radius was less than 80 feet.

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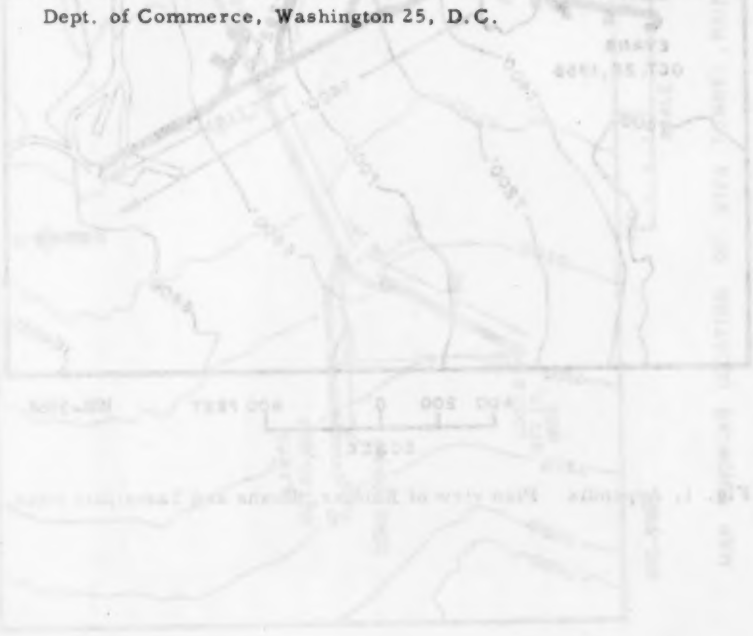
Note: ITR and WT reports are available from the Office of Technical Services, Dept. of Commerce, Washington 25, D.C.



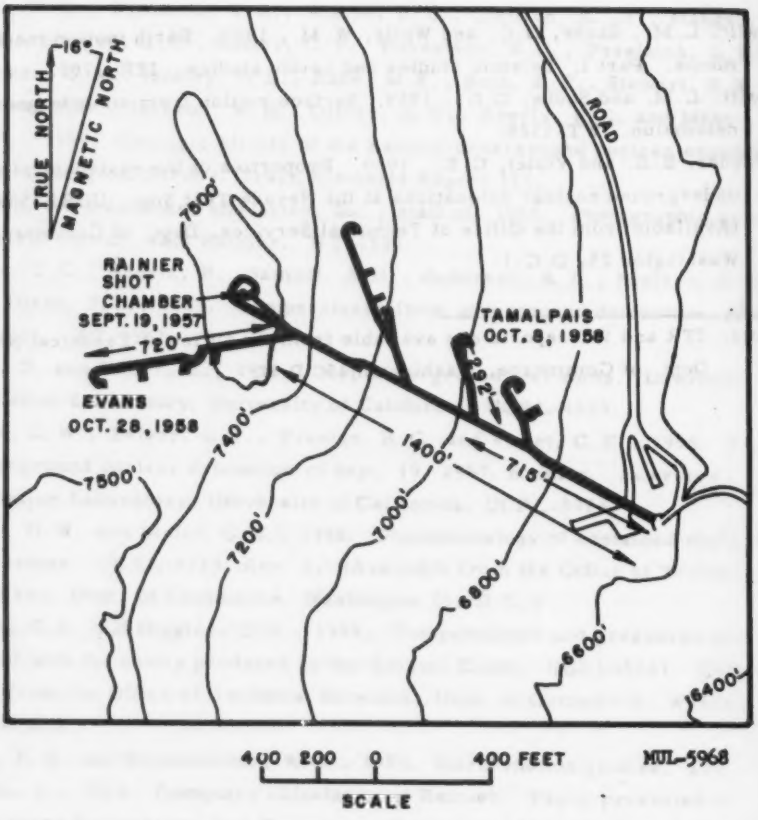
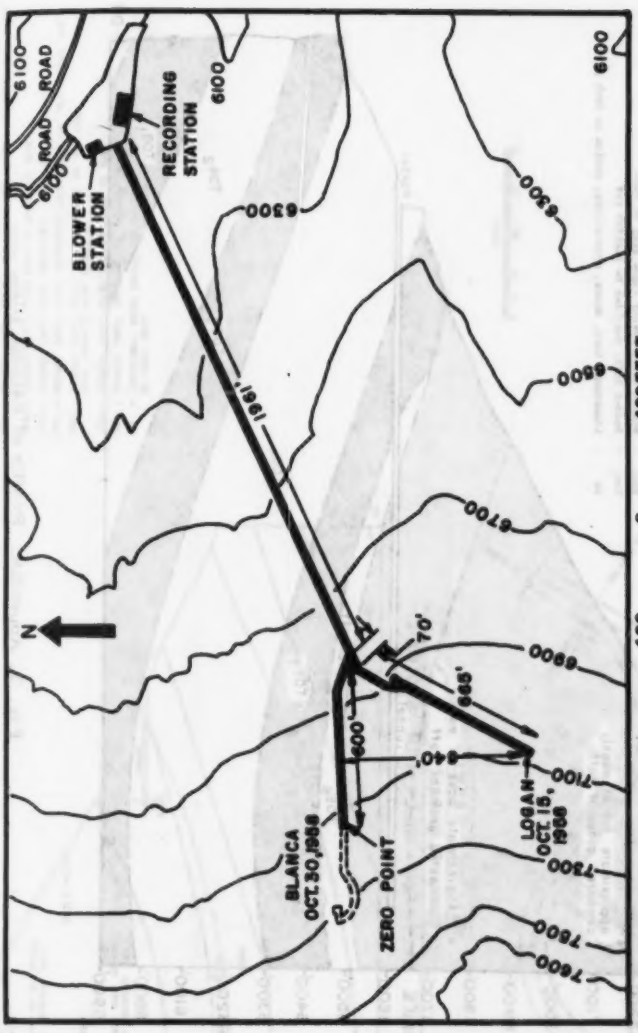


Fig. 1, Appendix. Plan view of Rainier, Evans and Tamalpais sites.



MAP SHOWING LOCATION OF U12e TUNNEL, RAINIER MESA, NYE COUNTY, NEVADA

Fig. 2, Appendix. Plan view of Blanca and Logan sites.

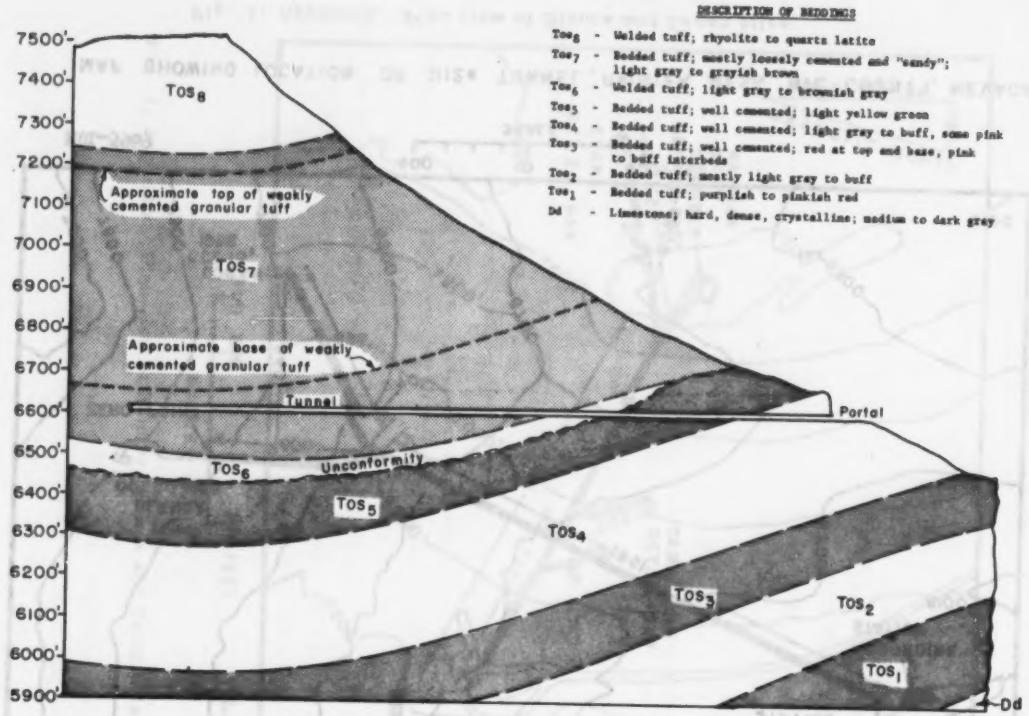


Fig. 3, Appendix. Profile of Rainier site.

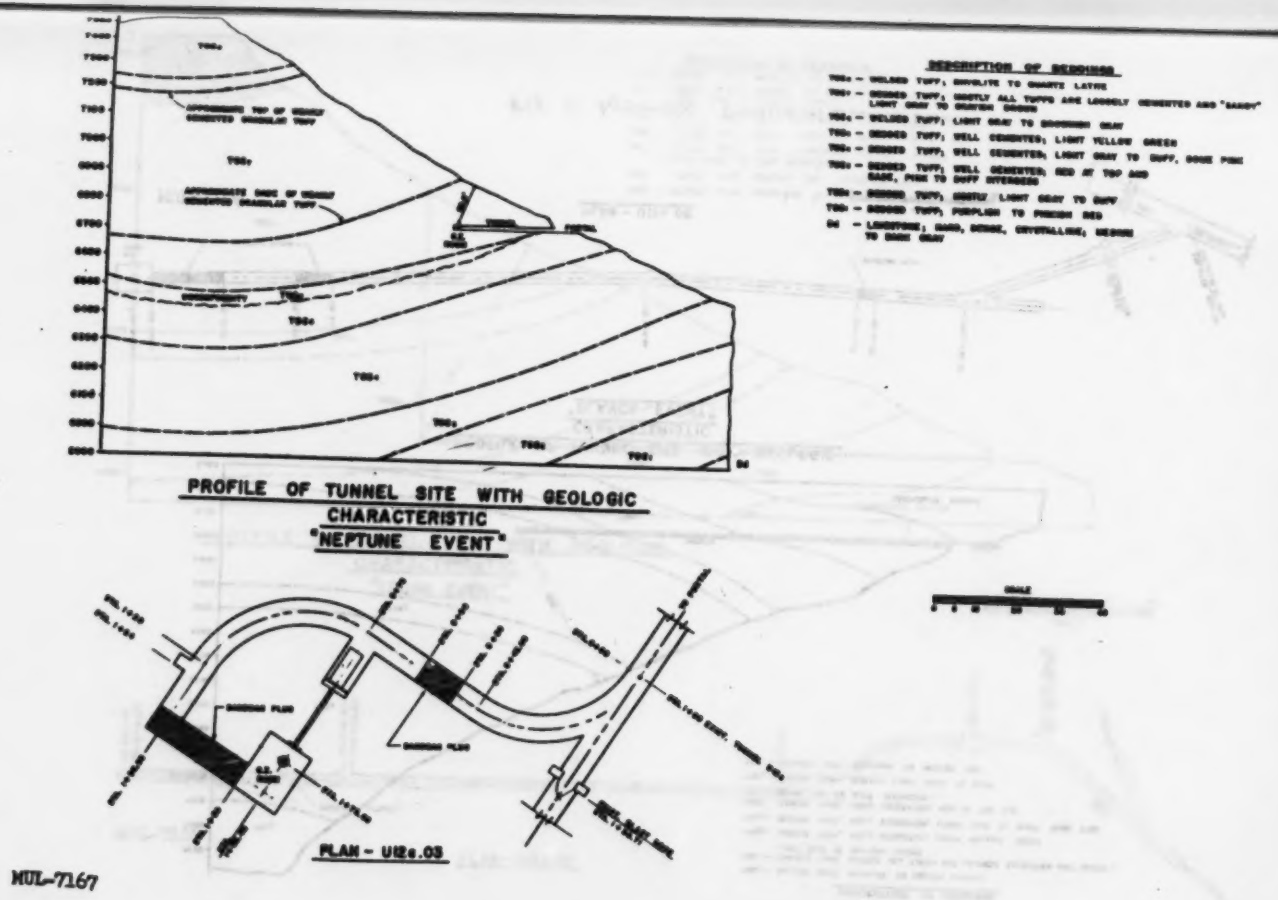


Fig. 4, Appendix. Plan of Neptune tunnel.

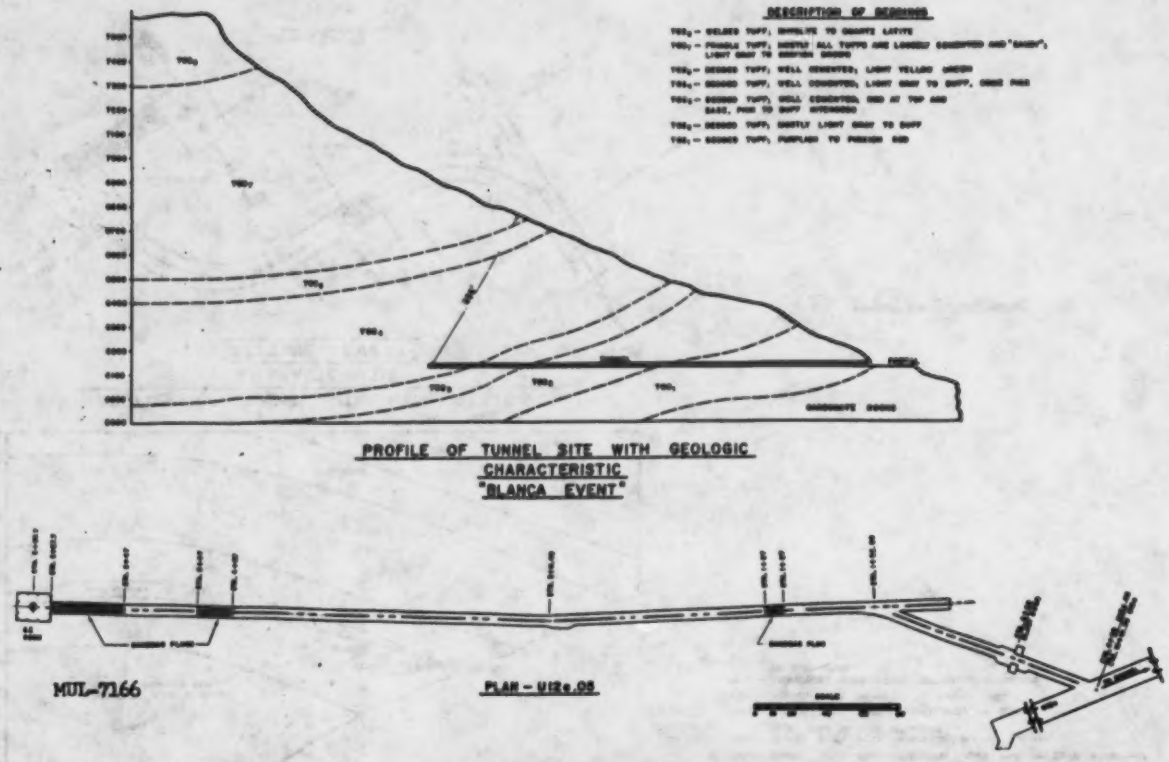


Fig. 5, Appendix. Profile of Blanca site.

Fig. 5, Appendix. Profile of Blanca Site.

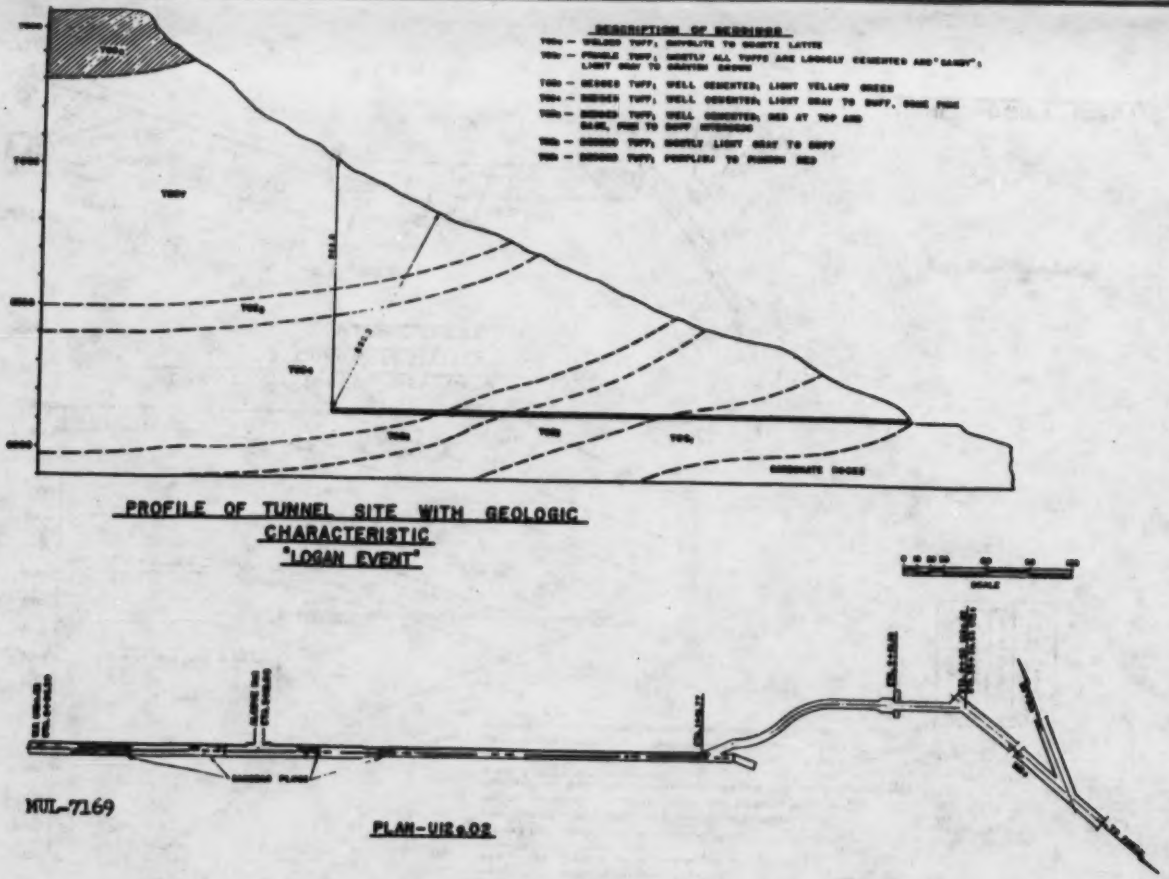
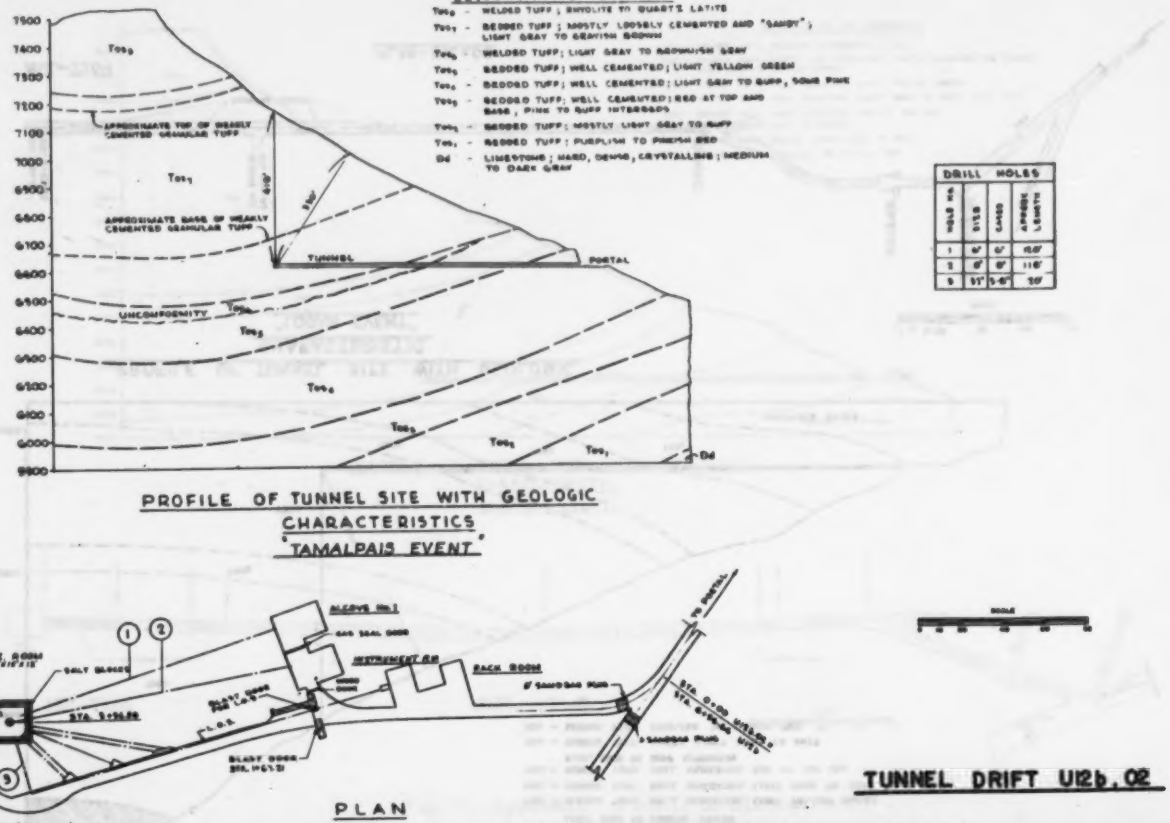


Fig. 6, Appendix. Profile of Logan site.



PROFILE OF TUNNEL SITE WITH GEOLOGIC CHARACTERISTICS 'TAMALPAIS EVENT'

Fig. 7, Appendix. Profile of Tamalpais site.

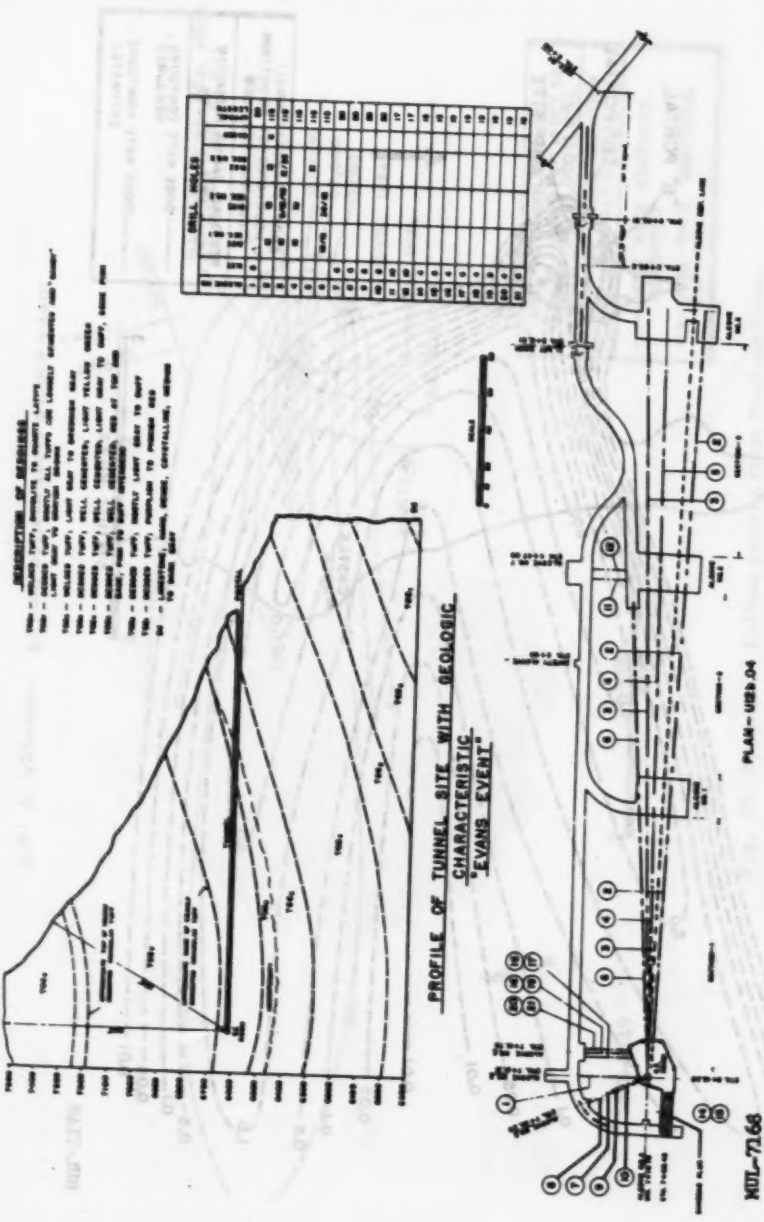


Fig. 7, Appendix. Profile of Tamalpais site.

Fig. 8, Appendix. Profile of Evans site.

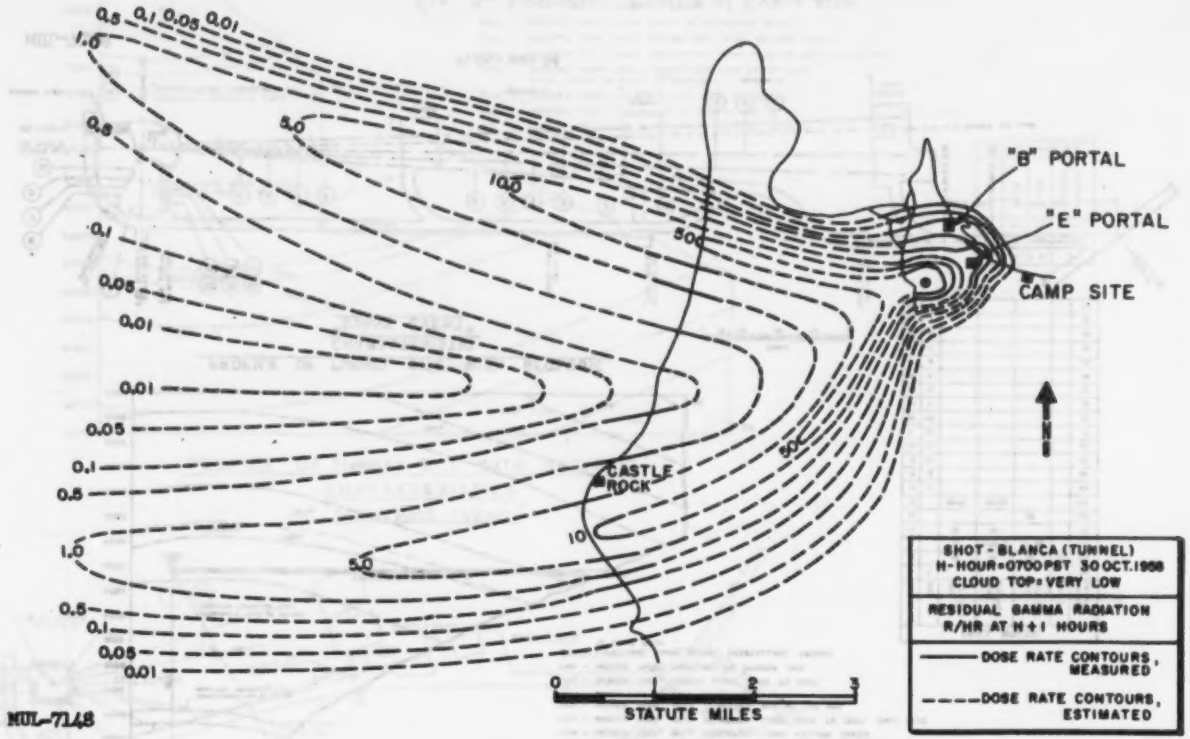


Fig. 9, Appendix. Fallout pattern from Blanca Event.

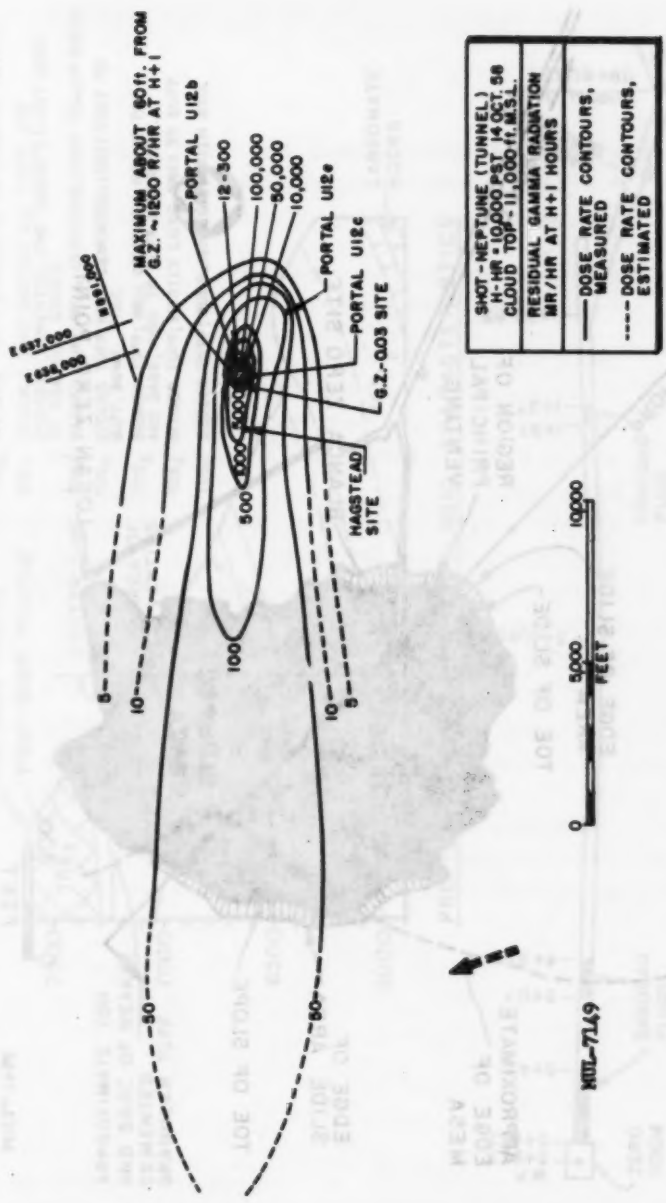


Fig. 10, Appendix. Fallout pattern from Neptune Event.

Fig. 9, Appendix. Fallout pattern from Blanca Event.

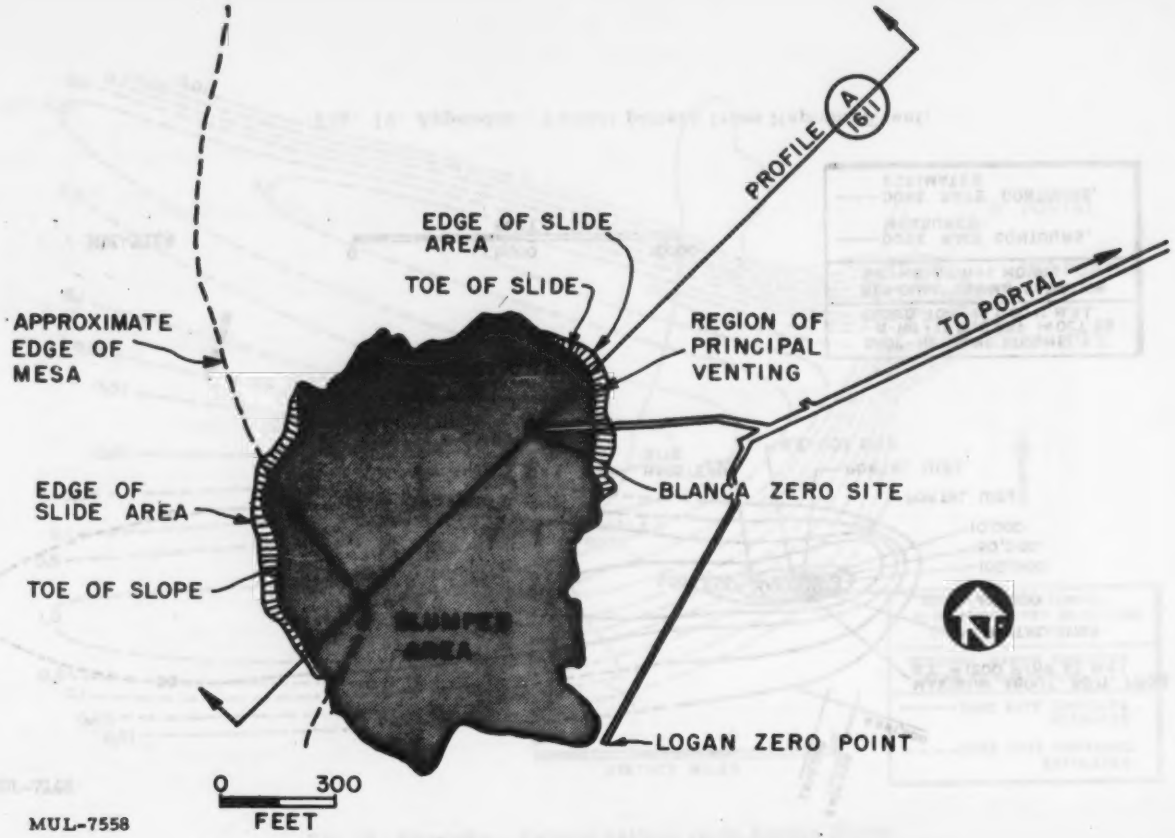


Fig. 11, Appendix. Pre- and post-shot profiles of Blanca site.

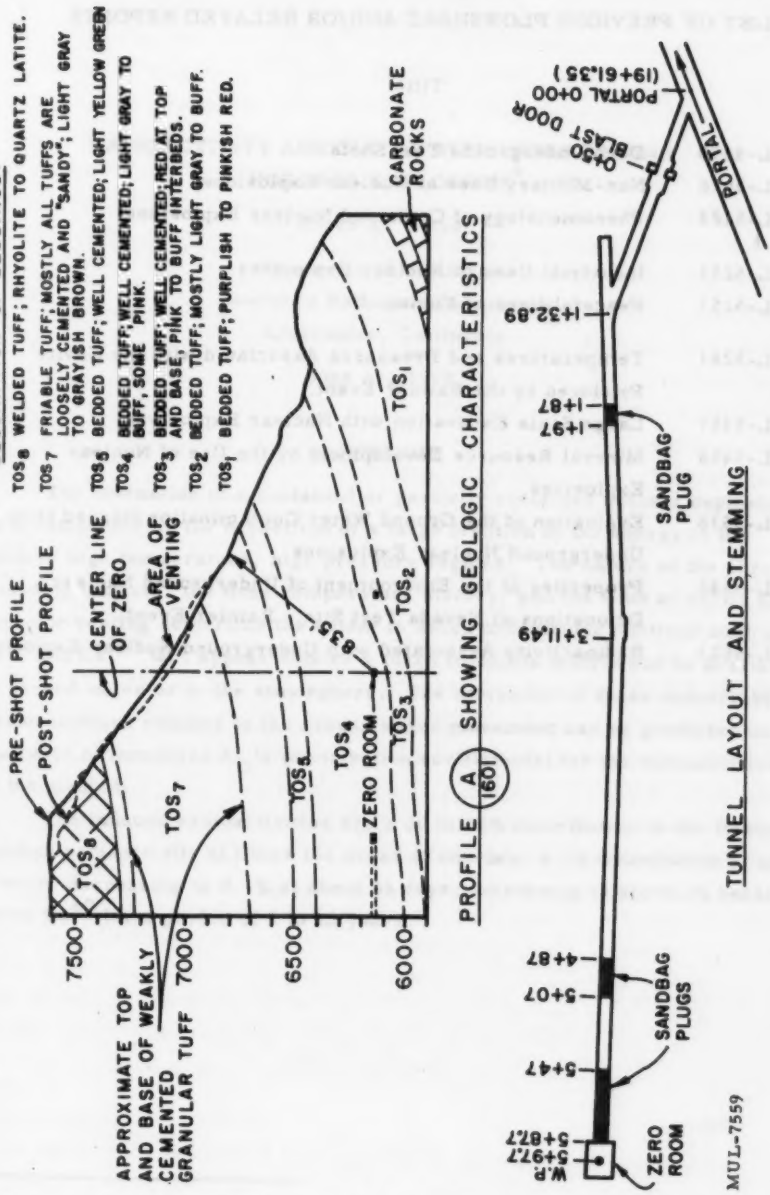


Fig. 12, Appendix. Plan view of Blanca slumped area.

Fig. 11, Appendix. Pre- and post-shot profiles of Blanca site.

LIST OF PREVIOUS PLOWSHARE AND/OR RELATED REPORTS

	Title
UCRL-4659	Deep Underground Test Shots.
UCRL-5026	Non-Military Uses of Nuclear Explosions.
UCRL-5124 Rev. 1	Phenomenology of Contained Nuclear Explosions.
UCRL-5253	Industrial Uses of Nuclear Explosives.
UCRL-5257 Rev.	Peaceful Uses of Fusion.
UCRL-5281	Temperatures and Pressures Associated with the Cavity Produced by the Rainier Event.
UCRL-5457	Large Scale Excavation with Nuclear Explosives.
UCRL-5458	Mineral Resource Development by the Use of Nuclear Explosives.
UCRL-5538	Evaluation of the Ground Water Contamination Hazard from Underground Nuclear Explosions.
UCRL-5542	Properties of the Environment of Underground Nuclear Detonations at Nevada Test Site. Rainier Event.
UCRL-5623	Radioactivity Associated with Underground Nuclear Explosions.

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RADIOACTIVITY ASSOCIATED WITH UNDERGROUND NUCLEAR EXPLOSIONS*

Roger E. Batzel
University of California
Lawrence Radiation Laboratory
Livermore, California

June 23, 1959

ABSTRACT

The detonation of a contained or partially contained nuclear explosion is accompanied by the deposition of a large fraction of the energy in the form of high temperature, high pressure regions. The nature of the surrounding medium, the time-temperature history, and the time of cavity collapse or venting determine the extent to which undesirable nuclides such as Sr^{90} and Cs^{137} will appear outside a fused insoluble matrix and be available to ground water or to the atmosphere. The movement of these undesirable radioactivities relative to the ground water movement can be predicted on the basis of measured K_D's (distribution coefficients) for the radioactivities in the medium.

The induced radioactivities are a 20 to 25% contribution to the fission product radioactivity at times the order of one day, a 1% contribution at about 1 week, decreasing to 0.1% at about 45 days, increasing to about 2% because of the Co^{60} for a period of 3 to 15 years.

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* The work was performed under the auspices of the U.S. Atomic Energy Commission.

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Introduction

The detonation of a contained or partially contained nuclear explosion is accompanied by the deposition of a large fraction of the energy in the form of high temperature, high pressure regions. The nature of the surrounding medium, the time-temperature history, and the time of cavity collapse or venting determine the extent to which undesirable nuclides such as Sr^{90} and Cs^{137} will appear outside a fused insoluble matrix and be available to ground water or to the atmosphere. The movement of these undesirable radioactivities relative to the ground water movement can be predicted on the basis of measured K_D's (distribution coefficients) for the radioactivities in the medium.

The induced radioactivities are a 20 to 25% contribution to the fission product radioactivity at times the order of one day, a 1% contribution at about 1 week, decreasing to 0.1% at about 45 days, increasing to about 2% because of the Co^{60} for a period of 3 to 15 years.

Explosion Phase

Assuming that a nuclear explosion is fired underground, just subsequent to the prompt energy release from the fission or thermonuclear reactions, the energy of the explosion is deposited in the immediately surrounding cavity at temperatures of the order of a few million degrees.[1] At these temperatures, the chemical behavior of the fission products is unimportant since the matter turns into a hot gas of ionized atoms and electrons.

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[1] G. W. Johnson and C. E. Violet, "Phenomenology of Contained Nuclear Explosions," Lawrence Radiation Laboratory, University of California, Livermore, California, UCRL-5124, Rev. 1, December 1958.

As the shock progresses into the wall of the cavity the first few feet of the surrounding medium is vaporized (about 3 feet for a 2-kiloton explosion) and mixed with the hot gases containing the fission products. As the hot gas cools to a temperature of about 5000°K condensed phases can begin to form, and this condensed phase is then deposited as a part of the molten layer on the wall of the cavity. The majority of the condensation is probably complete in times of the order of milliseconds. Left in the gas phase will be water vapor, noncondensible gases, including rare gases from the fission process and the more volatile fission products and volatile constituents of the medium.

The details of the above phenomena will depend on the time-temperature history, the degree of containment and associated collapse phenomena, and the nature of the medium in which the explosion takes place. If the cavity collapses or vents at a time when the pressure and temperatures are still high, the major fraction of the material in the gas phase will escape from the immediate highly radioactive molten zone.

Fission Process

The prompt energy produced in fission including kinetic energy of the fission fragments, prompt gamma rays, and neutrons is 179 Mev.[2] A kiloton is defined as 1.0×10^{12} calories or 4.185×10^{19} ergs and on the basis of 179 Mev per fission, there are 1.46×10^{23} fissions per kiloton. In addition to the prompt energy from fission, there is an average of about 22 Mev of additional energy which results from decay of the fission products. About 50% appears in the form of gamma rays, about 17% as beta decay energy and the other 33% as neutrinos associated with the beta decay process. About 7 Mev of the beta plus gamma decay energy appears in the first 20 minutes after detonation.

The fission of about 55 grams of Pu^{239}, U^{238}, or U^{235} yields an energy equivalent of 1 kiloton. For example a 1-megaton nuclear explosion with a fission-to-fusion ratio of 0.05 has a fission yield of 50 kilotons with its associated 2750 grams of fission products. These 2750 grams of fission products contain about 50 grams of Sr^{90} and are the equivalent of the waste fission products from approximately 2 3/4 days' operation of a 1000-megawatt reactor.

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[2] S.R. Gunn, H.G. Hicks, H.B. Levy, and P.C. Stevenson, Phys. Rev. 107, 1642 (1957).

The detonation of a nuclear explosion produces fission products in proportion to the fission yield of the explosion and these fission products are distributed according to the typical fission yield curve shown in Fig. 1. The general characteristics of this fission yield curve are the same for the fission of U^{238}, U^{235}, or Pu^{239}.

It is necessary to consider the elemental form of the fission products at the time of cavity venting in order to estimate the fraction of the radioactivity which is in the gaseous state. Table I illustrates the contribution of elements as percentages of the total radioactivity at various times after the detonation. These data are taken from the calculations of Bolles and Ballou[3] and apply to products from the thermal fission of U^{235}.

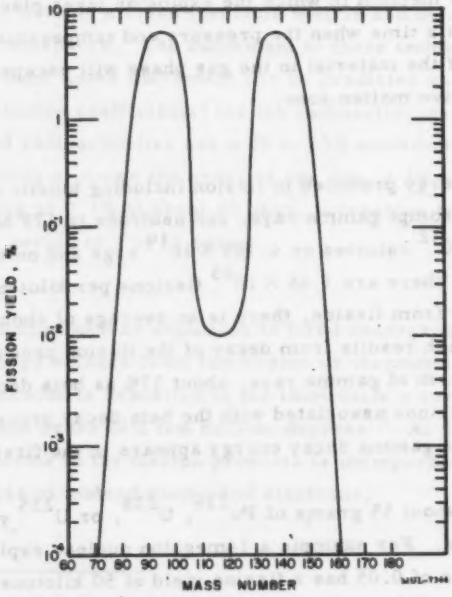

Fig. 1. Yield-mass curve for thermal fission of U^{235}.

[3] R.C. Bolles and N.E. Ballou, "Calculated Activities and Abundances of U^{235} Fission Products," USNRDL-456, August 30, 1956.

TABLE I. PERCENTAGE CONTRIBUTION OF ACTIVITY OF ELEMENTS TO TOTAL RADIOACTIVITY*

Element	10 sec	30 sec	1 min	5 min	30 min	1 hour
Kr	3.8	5	5.8	4.3	2.5	4.2
Xe	2.6	3.8	4.6	9	5	3.5
Y	11	9	8	4.6	7	5.0
Zr	12	7	3.5	--	--	--
Ba	7	2.6	2.4	8	9	8
Sr	6	4.0	5	11	4.0	3.7
Cs	7	7	7	8	8	8
Rb	7	8	8	11	7	4.8
La	9	8	4.0	2.8	9	10
Nb	10	12	11	8	5	6
Ce	4.7	3.0	1.0	2.5	5	4.4
Br	3.3	5	6	2.2	--	1.0
I	4.0	6	7	3.5	3.5	7.0
Mo	3.0	6	6	5	7	3
Te	2.7	2.5	2.0	3.5	9	14
Se	1.5	1.0	--	--	--	--
Pr	1.7	3.7	5	4.6	3.7	5
Sn	1.1	--	--	--	--	--
Tc	1.2	4.0	8	5	9	7
Sb	1.0	2.3	3.7	5	2.3	2.0
Nd	--	--	--	--	--	1.0

*Radioactivities contributing less than 1% of the total radioactivity are not included.

It is obvious from Table I that a large fraction of the radioactivity exists in the form of noble gases or somewhat volatile elements on time scales which should apply to situations in which cavity venting would occur. The noble gases will not condense until decay to another element has occurred, and the more volatile elements will not condense until the temperature is lowered, or a decay to a more refractory element occurs. The following are typical examples of fission product decay chains:

$$Kr^{89} \xrightarrow{3.2\ min} Rb^{89} \xrightarrow{40\ sec} Sr^{89} \xrightarrow{54\ days} Y^{89}$$

$$Kr^{90} \xrightarrow{33\ sec} Rb^{90} \xrightarrow{2.7\ min} Sr^{90} \xrightarrow{28\ yr} Y^{90} \xrightarrow{64\ hr} Zr^{90}$$

$$I^{137} \xrightarrow{22\ sec} Xe^{137} \xrightarrow{3.8\ min} Cs^{137} \xrightarrow{30\ yr} Ba^{137}$$

As an example for the mass-90 chain which is formed in fission, most of the material which finally exists as Sr^{90} is produced in the primary fission as Kr^{90} (about 80% with smaller amounts formed directly as Br^{90} or Rb^{90}). Thus, if the cavity vents in times comparable to the half life of the Kr^{90} a major fraction of the final Sr^{90} will escape the molten material along with the other gases.

Measurements made on debris from several of the explosions at the Nevada Test Site yield the following typical information:[4]

Strontium-89	—	3-10% in the major part of the fused tuff, enriched in the rubble by several-fold and in the vented debris by nearly an order of magnitude.
Strontium-90	—	20-30% in the fused tuff, vented debris enriched by 5-fold, local fallout less enriched.
Yttrium-91	—	30-50% in the fused tuff, vented debris and rubble enriched several-fold.
Zirconium-95	—	70-100% in the fused tuff, rubble enriched.
Cesium-137	—	20-40% in the fused tuff, vented material enriched by several-fold.
Barium-140	—	30-60% in fused tuff decreasing as yield increases, vented debris enriched several-fold.
Cerium-144	—	~100% in the fused tuff.
Neodymium-147	—	~100% in the fused tuff, precursors are rare earths.

Completely Contained Explosions

Based on the above discussion, even with the formation of an insoluble glassy matrix in which the major fraction of the fission products is incorporated, a large fraction of the Sr^{90} and Cs^{137}--that fraction which exists as a rare gas at the time of cavity collapse--will not be incorporated but will be distributed

[4] R.H. Goeckermann, University of California, Lawrence Radiation Laboratory, private communication.

with the other gases at the time the cavity vents. Thus appreciable amounts of Sr^{90} and other nuclides with rare gas precursors or nuclides of volatile elements would be expected to be deposited at appreciable distances from the highly radioactive zone and to be distributed on the surface of the broken medium as decay products of the rare gas precursors.

Partially Contained Explosions

Using the same reasoning which was applied to contained nuclear explosions, depending on the time and extent of venting of a partially contained explosion, the fraction of radioactive debris which does vent to the atmosphere should be rich in the rare gas and more volatile fission products. Sr^{90} and Cs^{137} should appear enriched with respect to the nuclides which do not have precursors which exist as rare gases at the time the radioactive debris is vented to the atmosphere.

For example, samples of the vented debris from Blanca (20-kiloton) detonation which vented approximately 0.3 to 0.5% of the total fission activity was enriched by about 5-fold in Sr^{90} indicating that about 1.5 to 2.5% of the total Sr^{90} formed in the explosion was actually released to the atmosphere. As the rare gases decay to atoms such as Rb^{90} and subsequently to Sr^{90}, these atoms would be expected to deposit rapidly upon the surface of the large amount of particulate matter which is blown out with the vented gas and to be scavenged from the atmosphere as the particulate matter falls out.

Ground Water Contamination

From the above discussion, it follows that the formation of an insoluble glassy material during the explosion does not guarantee the trapping of all the undesirable radioactivities. In fact, large fractions of two of the more undesirable nuclides from a biological point of view, Sr^{90} and Cs^{137}, will appear outside the fused material and in the broken material and regardless of arguments of the existence of fused, glassy, insoluble material in which the majority of the other fission products are contained, these nuclides will be accessible to ground water.

Higgins[5] in his paper on ground water discussed the fact that ions such as Sr^{90} and Cs^{137} are selectively absorbed from ground water by most naturally

[5] G.H. Higgins, "Evaluation of the Ground Water Contamination Hazard from Underground Nuclear Explosions," Lawrence Radiation Laboratory, University of California, Livermore, California, UCRL-5538, April 8, 1959.

occurring minerals and that these ions distribute themselves between water and minerals according to the following law

$$K_D = \frac{A_S \times M_w}{A_w \times M_S}$$

where K_D is the distribution coefficient, A_S and A_w are the activities in the mineral and water respectively, and M_w and M_S are the masses of water and mineral respectively in equilibrium. Given K_D of a nuclide, it is possible to calculate the average flow rate of the activity as a function of the ground water flow rate.

$$F_A = F_w \frac{1}{1 + K_D \rho}$$

where ρ is the ratio of the mass of mineral per unit volume to the mass of water per unit volume. $\rho = 10$ represents the typical situation in most situations in which ground water occurs. K_D's, distribution coefficients, for natural occurring minerals range from minima of about 100 (limestone) for Sr^{90} to 100,000 for Ce^{144}. With a typical flow rate for ground water of 3 feet per day for example, assuming $K_D = 300$ and $\rho = 1$, the average flow rate of Sr^{90} in the medium would be

$$F_A = 3 \text{ ft/day} \times \frac{1}{1 + 300} = 0.01 \text{ ft/day}$$

so that in a time equal to the half life of Sr^{90} (28 years) the Sr^{90} activity would have moved about 100 feet. See the Appendix for an example of the effect of the distribution coefficient on the concentration of Sr^{90} in ground water.

On the basis of the above considerations, it is possible by having a detailed knowledge of the hydrology of an area and by making laboratory measurements on minerals which will be in contact with the ground water of the K_D's (distribution coefficients) for the biologically undesirable nuclides to predict the fate of these radioactivities in the ground water. In general, because of the ion exchange characteristics of naturally occurring media, ground water contamination does not appear to present any serious hazard, nor does the ground water contamination problem appear to place any serious limitations on the use of nuclear explosives.

Induced Radioactivities

Based on the assumption that $\sim 1 \times 10^{23}$ neutrons per kiloton of yield are emitted from a nuclear explosion and that these 1×10^{23} neutrons are captured

in the surrounding medium, it is possible to estimate the levels of radioactivity induced in a typical medium surrounding a nuclear explosion. The major fraction of the induced radioactivity would be expected to occur in the first 2 or 3 feet of medium and to be included in the initially vaporized material.

Table II gives the typical medium composition chosen and it is the same as that given in Brian Mason, Principles of Geochemistry, John Wiley and Sons (1952). For comparison, the results of an analysis of Nevada sand is shown. Oxygen is not included since the oxygen absorbs substantially less than 1% of the neutrons. The composition in the case of the typical medium includes 20% by weight water.

TABLE II. MEDIUM COMPOSITION

Typical Medium		Nevada Sand	
Element	Abundance by Wt %	Element	Abundance by Wt %
Si	50	Ca	~30
Al	14.5	Si	~25
Fe	9	Al	~20
Ca	6.4	Fe	~10
H	5.1	Na	~ 8
Na	4.9	Mg	~ 2
K	4.7	K	~ 3
Mg	3.7	Ti	0.1 - 1%
Ti	0.6	B, Mn, Cu	0.01 - 0.1%
P	0.18		
Mn	0.18		
Co	0.0042		

The neutrons captured in the typical medium were distributed according to the atom percent of the element present and the thermal neutron capture cross sections for the element.[6] With 20% by weight water, most of the neutrons are thermallized before capture occurs, and about 60% of the neutrons

[6] D.J. Hughes and R.B. Schwartz, "Neutron Cross Sections," Brookhaven National Laboratory; Upton, New York, BNL-325, July 1, 1958.

are captured by the hydrogen of the water in this typical medium. The important radioactive nuclides produced and the percent of the neutron capture leading to these nuclides is shown in Table III.

TABLE III. RADIOACTIVE NUCLIDES PRODUCED

Element	Nuclide Produced	Half Life[7]	Gamma[7] Energy	Percent of Neutron Captures leading to Nuclide
Na	Na^{24}	15 hours	4.0 Mev	3.7%
Al	Al^{28}	2.3 min	1.8 Mev	2.6%
Mn	Mn^{56}	2.6 hours	1.8 Mev	1.3%
Fe (0.33% Fe^{58})	Fe^{59}	45 days	1.3 Mev	0.015%
Co	Co^{60}	5.2 years	2.5 Mev	0.09%

In Table IV are listed the number of curies per kiloton of these nuclides estimated to be produced.

TABLE IV. CURIES PER KILOTON OF NUCLIDES PRODUCED

Nuclide	Curies	(Curies) × (Gamma Energy)
Na^{24}	1.3×10^6	5.2×10^6
Al^{28}	3.5×10^8	6.3×10^8
Mn^{56}	2.6×10^6	4.7×10^6
Fe^{59}	$\sim 10^2$	$\sim 1.3 \times 10^2$
Co^{60}	~10	~25

The number of (curies) × (gamma ray energy) is a measure of the relative biological effectiveness of the gamma rays. Figure 2 is a comparison of these radioactivities as a function of time with the fission product radioactivities from 1 kiloton of fission yield. The induced radioactivities are a 20 to 25% contribution to the fission product radioactivity at times the order of one day, a 1% contribution at about 1 week, decreasing to 0.1% at about 45 days, increasing to about 2% because of the Co^{60} for a period of 3 to 15 years.

[7] D. Strominger, J.M. Hollander, and G.T. Seaborg, Rev. Modern Phys. 30, 585 (1958).

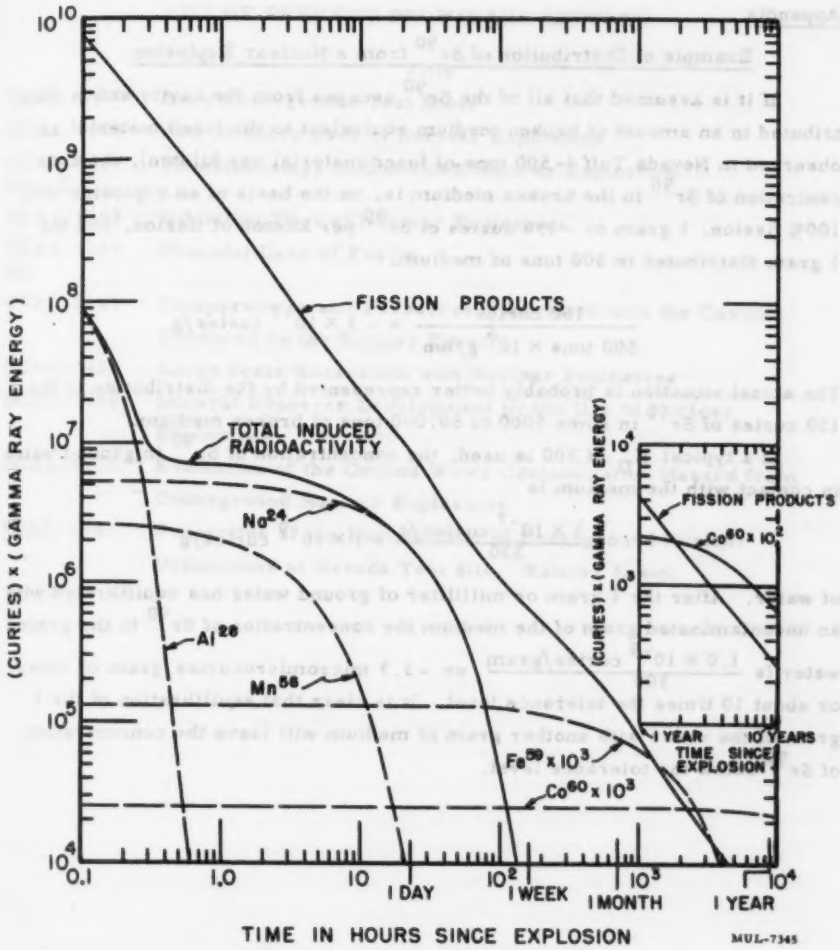

Fig. 2. Comparison of induced radioactivity and fission product radioactivity from a one kiloton nuclear explosion.

Appendix

Example of Distribution of Sr^{90} from a Nuclear Explosion

If it is assumed that all of the Sr^{90} escapes from the cavity and is distributed in an amount of broken medium equivalent to the fused material as observed in Nevada Tuff (~500 tons of fused material per kiloton), the concentration of Sr^{90} in the broken medium is, on the basis of an explosion with 100% fission, 1 gram or ~150 curies of Sr^{90} per kiloton of fission, and the 1 gram distributed in 500 tons of medium,

$$\frac{150 \text{ curies}}{500 \text{ tons} \times 10^6 \text{ g/ton}} = \sim 3 \times 10^{-7} \text{ curies/g}$$

The actual situation is probably better represented by the distribution of the 150 curies of Sr^{90} in some 5000 to 50,000 tons of broken medium.

If a typical K_D of 300 is used, the concentration of Sr^{90} in ground water in contact with the medium is

$$\frac{3 \times 10^{-7} \text{ curies/g}}{300} = 1 \times 10^{-9} \text{ curies/g}$$

of water. After the 1 gram or milliliter of ground water has equilibrated with an uncontaminated gram of the medium the concentration of Sr^{90} in the ground water is $\frac{1.0 \times 10^{-9} \text{ curies/gram}}{300}$ or ~3.3 micromicrocuries/gram of water or about 10 times the tolerance level. It is clear that equilibration of the 1 gram of the water with another gram of medium will leave the concentration of Sr^{90} below the tolerance level.

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LIST OF PREVIOUS PLOWSHARE REPORTS

	Title
UCRL-4659	Deep Underground Test Shots
UCRL-5026	Non-Military Uses of Nuclear Explosions
UCRL-5124 Rev. I	Phenomenology of Contained Nuclear Explosions
UCRL-5253	Industrial Uses of Nuclear Explosives
UCRL-5257 Rev.	Peaceful Uses of Fusion
UCRL-5281	Temperatures and Pressures Associated with the Cavity Produced by the Rainier Event.
UCRL-5457	Large Scale Excavation with Nuclear Explosives
UCRL-5458	Mineral Resource Development by the Use of Nuclear Explosives
UCRL-5538	Evaluation of the Ground Water Contamination Hazard from Underground Nuclear Explosions
UCRL-5542	Properties of the Environment of Underground Nuclear Detonations at Nevada Test Site. Rainier Event.

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EVALUATION OF THE GROUND WATER CONTAMINATION HAZARD FROM UNDERGROUND NUCLEAR EXPLOSIONS*

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April 8, 1959

ABSTRACT

Radioactivities in ground water collected at Nevada Test Site since the underground nuclear explosions in Operations Plumbbob and Hardtack Phase II have not been significantly above background. This is due to the formation of silica glass by the explosion, and the ion-exchange properties of fission products in normal earth minerals and water. The glass formed by the high shock pressures releases less than ten percent of its radioactivity when leached with water, and the rock minerals crushed by the explosive forces adsorb several tens of milliequivalents of fission products per hundred grams. The distribution coefficients for adsorption range from 50 to 500,000 depending on the particular fission product and mineral. A theory pertaining to the flow of activity in an ion-exchange medium is developed, and equations for application of laboratory data to field experiments are included. Some of the available distribution coefficients are tabulated from the literature on waste disposal. It is concluded from existing information that hazards arising from underground explosions in other media will not give rise to serious contamination problems. Until more experience is gained, measurements of aquifer properties should be made prior to planned explosions to determine that safe conditions exist in each particular case.

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INTRODUCTION

Several underground explosions at the Nevada Test Site during Operations Plumbbob and Hardtack Phase II occurred in a volcanic tuff which has low permeability and hence is not a good aquifer, but at least two of them (Blanca and Logan) occurred below the local water table. Subsequent to the detonations water has been sampled from drill holes transecting the exact explosion sites, and from tunnels which have been dug into the crushed and collapsed zones close to the explosion sites. The radioactivity in this water has ranged from 1 to 10 micro-microcuries per milliliter. This range of radioactivity is about that expected as background in southern Nevada and is well below the maximum allowable for human consumption.

This low radioactivity in the ground water is understandable from consideration of the effects of the explosions on the medium, of the ion-exchange behavior of minerals and of the nature of underground water flow. The details of these three areas of considerations are discussed separately.

I. THE NUCLEAR EXPLOSION AND ITS EFFECT ON THE IMMEDIATE SURROUNDINGS

If nuclear explosions are triggered underground, they produce local effects which are thought to be relatively independent of the rock type and geological formations present. In most, if not all, of the envisioned applications of nuclear explosives, the explosion will occur at depths which will be sufficiently large to contain more than 99% of the radioactive debris in the formations immediately adjacent to the explosion, and these formations will necessarily be subjected to the heats and pressures developed during the explosion.

When a nuclear explosive is fired in a small chamber surrounded by a dense material, such as rock or soil, the walls are subjected to shock pressures in the order of several million atmospheres and are heated to several thousand degrees °C. This high pressure and temperature serves to melt and vaporize the first few feet of material outward from the explosion chamber, and the bulk of the radioactive debris is contained in this fused material.[1] Beyond the melted region, the shock pressure continues to do considerable damage to the surrounding formations as it passes through them, and its intensity falls off rapidly since work is done on the medium until the pressure reaches a value equal to the crushing strength of the rock. Thus one would expect the fused material containing the bulk of the radioactive debris to be surrounded by a zone of finely pulverized, unclassified, highly compressed material.

The extent of these several regions depends on the rock type and amount of explosive. In tuff in which the Nevada experiments in Operations Plumbbob and Hardtack Phase II were conducted, the radius of the fused region amounted to about 15 $W^{1/3}$ feet and the radius of the highly compressed pulverized region extended to about 100-150 $W^{1/3}$ feet, where W is the amount of nuclear explosive in kiloton equivalents. The difference between tuff and other rocks or aggregate materials should not account for very large differences from these radii since the radii are related to the cube root of the energy or pressure, and changes of a factor of eight in rock strength should account for changes of a factor of two in the radii at which various effects are noted.

Another noticeable effect produced by the underground explosion is the formation of a cavity. The high shock pressures and the gases left at the center of the explosion chamber at high temperatures and pressures combine to form the cavity, and the gaseous fission products, such as krypton and xenon, are trapped in this cavity. If the cavity collapses, these radioactive gases escape. Fortunately, the fission products which are permanent gases, such as Kr^{85}, are not biologically dangerous because they are rapidly diluted if the gases reach the atmosphere and are biologically inert. Some of the gases present during times shorter than a few minutes, however, decay into isotopes which are of concern in their effect on the biosphere. Most important among these are the 33-second Kr^{90} which

decays to Sr^{90} and 3.8-minute Xe^{137} which decays to Cs^{137}.

In cases in which the collapse of the cavity does not reach the ground surface, the Sr^{90} and Cs^{137} would be adsorbed by fragment surfaces throughout the collapsed permeable region but contained from escape to the atmosphere. The degree to which the gaseous products would be contained in the fused material would depend primarily on the length of time the cavity stood before collapse. Analysis of debris from the Rainier explosion fired during Operation Plumbbob indicates that a large percentage of the Sr^{90} and Cs^{137} was contained in the glass. Glass debris from larger explosions which occurred in the same material as Rainier seems to contain less Sr and Cs, indicating earlier collapse.

In case of vented underground nuclear explosions the gaseous activities would escape and decay and should rapidly adhere to the surfaces of the relatively large dust particles which will be formed when the gases break through the ground surface. These large particles should fall out relatively close to the site of the detonation because the dust cloud should be relatively cool compared to the cloud produced by a nuclear explosion which occurs in air above ground, and therefore not rise to an appreciable altitude, and because they are probably ten times larger (1000 times heavier) than ordinary fission product debris from air or near-surface bursts.[2] Activity which is deposited on the ground surface does not reach the ground water supply in any reasonable length of time. Russell, et al.[3] state that "the very small amount of leaching observed in soil is indicative that the movement of fallout in subsoil drainage water is likely to be a very minor source of hazards, at any rate in soils of high base-exchange capacity."

The production of fused material is important in reducing the potential contamination of ground water, since even at early times 80% of the fission products are not gaseous.

If the medium in which the explosion occurs contains appreciable alumina and silica, and does not contain excessive sodium or potassium, a glass results from the melting and these glasses have been shown in several experiments to be extremely impervious to leaching. Amphlet and Warren[4] found that sands which had adsorbed activity by ion-exchange processes and were then sintered at 1000°C for 8 hours retained 99.87% of all fission

products as well as Sr^{90} and Cs^{137} even after being equilibrated with one hundred times their volume of water for four months. It was also evident from their experiments that the rate of extraction of additional activity was dropping from the initial rate of 0.1% per week to well below 0.003% per week at 4 months so that something like 99.5% of all the activity contained in the glass would not be available to ground water in the next few centuries. The data of Bond and Clark[5] confirm that these data apply in general to the fused materials produced by an underground nuclear explosion.

If the explosion took place in a limestone medium, the fused material might not be so intractable to leaching since fused calcium and magnesium oxides tend to react with water. Insoluble glasses could be produced, of course, by adding a few feet of silica sand as tamping, but this expedient would probably be unnecessary in all but the most difficult cases because of the nature of water flow in limestone and because of the ion-exchange adsorption of dangerous activities.

The effects of the explosion may be summarized by saying that the explosion itself serves to prevent the contamination of ground water in two ways. This occurs first because the bulk of the activity is bonded in an insoluble, unleachable glass produced from many materials; and second because a zone of finely divided unclassified material is produced and which should act as an effective aquiclude[7] (impermeable barrier to water flow) between possible ground water flow and the activity. The effects of this crushed region on water flow are discussed below.

II. FLOW OF RADIOACTIVE IONS IN THE EARTH'S CRUST

In every case, minerals and soils which have been studied adsorb and exchange a significant number of free ions. This effect was noted and has been under more or less constant study since 1850 when the first studies on soil ion exchange were reported by H. S. Thompson and by J. T. Way in the Journal of the Royal Agricultural Society. The remarkable thing about this is that at that time the science of chemistry was not well organized, so that even such now obvious things as the existence of acid hydrogen ions were not suspected. In spite of this disadvantage, more than half of the work performed in the first ten years of investigation has stood later scrutiny and is accepted today.[8]

At the present time it is sufficient to say that exact relationships between minerals and ions in water can be stated, and that if the general nature of the minerals and flow of water is determined experimentally, the transport of fission products or induced activities can be calculated with sufficient accuracy and dependability to guarantee radiological safety.

The rules which govern transport of ions in soils and minerals may be divided into three general subcategories. These apply to the capacity of the minerals for ion exchange, the distribution of various ionic species between the aqueous and solid phases, and the kinetics of ion transport in an ion-exchange medium.

A. The Capacity of Minerals for Ion Exchange

Soils and mineral particles or fragments acquire their ion exchange capacity from two distinctly different sources. The first is the ability of impervious crystalline assemblages of atoms to hold charged ions by electrostatic attraction. In this way the outer negative oxygen atoms of finely divided pure quartz produced by grinding large crystals hold ions on the surfaces.[6]

The second source of ion-exchange capability comes from actual stoichiometric chemical reaction. In this way montmorillonite clays exchange a part of their inter-crystalline Na^+, K^+, Ca^{++} or Mg^{++} with ions in solution. This kind of ion exchange is more nearly a volume phenomenon in that there are exchangeable ions throughout the crystal volume. If the particle sizes are large, however, the rates of exchange with interior ions are very slow so that not all are available to water flowing at an appreciable rate. A certain amount of ion migration goes on within the crystal, though, so that different ions are in the outer available sites at various times.

It is evident then that any sample of naturally occurring material will exchange ions by both mechanisms since in general many different minerals and particle sizes will be present. The range of experimentally determined capacities for naturally occurring and artificial minerals of clay-particle-size range varies from about 1 to 150 milliequivalents per hundred grams (meq./100 g.). The portion of this capacity due entirely to surface electrostatic effects can be determined from the data of Evans[6] and is about 0.5 meq. per square meter of surface. In the particle size range for which the capacities are stated above, surface effects account entirely

for the values from one to 2 meq./100 g. of sample quoted as the lower limit of capacity.

Since one megaton of fission produces about 1×10^6 meq. of fission products which would be distributed in at least 5×10^{11} g. of material, only 2×10^{-4} of the capacity would be used for complete adsorption even if the minimum capacity (1 meq./100 g.) is assumed. Under these conditions the chemical effect of the fission products on the soil and ground water chemistry is seen to be negligible and in fact "tracer" conditions are reached.

Table I contains a list of several experimentally determined ion-exchange capacities. These are indicative of the usual variation, and much more extensive information is available in several standard references on either ground water or clay mineralogy.[7]

B. The Distribution of Various Ions Between Solutions and Earth Minerals

In any chemical reaction, such as the adsorption and desorption of an ion onto a solid, an equation can be written to represent the process. The usual equilibrium equations must apply and a reaction constant can be derived.

Thus if M^{+m} and A^{+n} represent ions of fission product activities and naturally occurring exchangeable minerals carrying charges $+m$ and $+n$, and X is assumed to be a reactive chemical radical in the earth mineral, the equation for exchange is

$$n\,M^{+m} + m(A\,X_n) \rightleftharpoons n(M\,X_m) + m\,A^{+n} \qquad (1)$$

and

$$K = \frac{\left[M\,X_m\right]^n \left[A^{+n}\right]^m}{\left[M^{+m}\right]^n \left[A\,X_n\right]^m} \qquad (2)$$

Ordinarily it is difficult to apply this equation to mineralogical processes because the real activities of ions in solids are difficult to determine. Since only 2×10^{-4} of the active sites are occupied by fission products, $\left[A^{+n}\right]$ and $\left[A\,X_n\right]$ may be assumed constant. The distribution coefficient K_d can therefore be written as

$$K_d = \frac{M X_m}{M^{+m}} \frac{V}{W} \quad (3)$$

where V is the volume of solution and W is the weight of minerals. The ratio of $M X_m / M^{+m}$ is the fraction of radioactive ions in the mineral phase divided by the fraction of radioactive ions in the water.

The value of K_d is a number which is easily determined in the laboratory by equilibrating a sample of mineral mixed with water with a small amount of tracer activity of the desired ion. These measurements have been made on many ions with many different kinds of soil and minerals and a few are summarized in Table I.

The implication of equation (3) is that in any mineral-water system such as an aquifer, there is a fixed ratio between the radioactivities in the liquid and solid phases. The values of K_d in Table I fall generally in the order of from 100 to several thousand so that at least one hundred times as much of the radioactivity is adsorbed as is in solution. Since only the solutions are moving in the earth, only a small portion of the ions adsorbed are transferred with the water.

Two generalizations about the values of K_d can be made from the data presented in Table I.

First, the value of K_d for the same isotope in different minerals correlates generally with the capacity of the mineral. This is easily understood since the K_d is expressed as a ratio per gram of mineral while the chemical equation requires that the concentration of active sites in the mineral be used. The ion-exchange capacity is in reality an expression of the concentration of active sites. Since the exchangeable ion may be Ca^{+2}, Mg^{+2}, K^{+1} or Na^{+1} in varying amounts, the correlation cannot be exact and it is not practical to try and define K_d in terms of the more proper variables. In general, K_d (quartz) < kaolin < illite < montmorillonite, although this relationship does not hold for all ions.

Second, the relative values of K_d for different ions in the same mineral

or soil are such that Ru < Sr < Cs < Y < Pu ≈ Ce, so that as the radioactive ions of these elements elute through soils or minerals, they will appear in this order at any point along their path, and the first element to expect in a well would be Ru.

It is implicit in the foregoing statements that the minerals which weather to the clay minerals discussed (i.e. illite, kaolinite, and montmorillonite) will be as effective or perhaps more effective as ion exchangers than their clay daughters, providing sufficient surfaces are available for exchange. At least in the region in near proximity to the explosion site, the high shock pressures are sure to produce sufficient surfaces by crushing.

While the K_d's listed in Table I apply in relatively pure water (~0.001 M impurities), several investigators have studied the effects of varying salt and pH.[6, 9, 10, 11, 12, 13] The effect of added salt in the water is not the same for each ionic species, but in general K_d decreases logarithmically with increasing salt concentration. Thus while K_d for the tracer Cs is about 5000 in relatively pure water on Hanford soil, it decreases to about 15 in saturated sodium chloride solution.[11] This effect is not so pronounced on Pu and Ce. Varying pH has very small effect between pH 2 and about 9, and causes a decrease in K_d as it varies beyond these limits. Most ground water would fall within this pH range.

This discussion has been confined to the adsorption of cationic species (base exchange) even though minerals also display some anionic exchange properties. Fortunately, the only fission product whose half life is longer than one year and which displays anionic properties is Ru, and it has been adequately studied[9] to demonstrate that it behaves primarily as a cation in soils although its adsorption is not entirely reversible.

There are a few radioactive species which are inert as regards their behavior in soil minerals. Tritium and the noble gases Kr and Xe would not be affected by ion exchange processes, but they have relatively little importance as potential hazards in an ecological sense. Tritium should, however, be the best ground water tracer available.

C. The Kinetics of Ion Transport in an Ion Exchange Medium

The potential hazard arising from ground water contamination is reduced by ion-exchange processes in two ways. First, the flow of a particular ion is markedly inhibited so that instead of moving with the ground

water, cationic radioactivities move at most only about one percent as fast as the ground water. Second, the concentration of the radioactivity is reduced as it finds its way throught the aquifer materials because the movement of any particular ion from the soil into the water is a statistical matter and a group of ions that start out together will move further and further apart after they exchange on and off the soil several times. These two effects are considered in detail below.

If the distribution coefficient K_d and flow rates of water F_w are known in a particular aquifer, it is a simple process to calculate the flow rates of any ionic species, F_a, from the expression

$$F_a = \frac{F_w}{1 + K_d \rho} \qquad (4)$$

where ρ is the ratio of the weight of mineral to volume of water per unit volume of aquifer material. Since ρ is not known exactly, it is convenient and very conservative to use a value of unity in calculation since the usual value is about 4 or 5. Any real earth mineral will in general have a density larger than one, so that the denominator in equation (4) would be larger than that obtained by assuming $\rho = 1$ and the flow of radioactivity would be actually slower than that calculated.

Using values from Table I and assuming a water flow of 10 feet per day in Hanford composite soil, the flow rate of Cs^{137} is 27 one thousands of an inch per day, while the flow of Pu^{239} on pure crushed quartz would be as large as about 1.5 inches per day.

Even this small retardation noted on quartz is sufficient to delay the appearance of plutonium at a well one mile from the source of contamination for 120 years. Cs^{137} would not be easily detectable one mile from the source of contamination in a soil similar to the Hanford material since it would take 6,600 years to get there and by that time would have undergone radioactive decay by a factor of about 10^{-90}.

The flow calculated from equation (4) is the <u>average</u> rate of transfer of ions. There will be some ions which flow slightly faster on the average, and some slightly slower. The effect of this random statistical motion is one of reducing the concentration at any point in the aquifer after some flow has occurred. With the aid of a computer it is possible to calculate the

distribution of activity as a function of distance and time. If it is assumed that all of the radioactivity is in a plane zone of arbitrary thickness oriented at right angles to the direction of flow, and that if it were possible to stop all time-dependent processes, the radioactivity in the water, A_w, would be

$$A_w = \frac{A_s}{\rho K_d} \tag{5}$$

where A_s is the activity in soil or mineral. A_s is very nearly the total activity when K_d is large, the fraction of radioactivity in the water may be represented by

$$\overline{A_w} = \frac{1}{\rho K_d} \tag{6}$$

Now if the zone is restricted so that it contains a unit mass of mineral, and a time cycle (c) is defined so that a unit volume of water just flows through the unit zone, ρ becomes one and

$$A_w = \frac{1}{K_d} \tag{7}$$

will be transferred to the next zone along the path of flow. The process is repeated in the second time cycle so that the fraction of activity in the third zone is $1/K_d$ times that in the second which is $1/K_d$ times that in the first or $(1/K_d)^2$ and the activity in the second zone is

$$A_2^2 = \frac{1}{K_d} + \left(1 - \frac{1}{K_d}\right)\frac{1}{K_d} - \left(\frac{1}{K_d}\right)^2$$

and that in the first zone is

$$A_1^2 = 1 - \frac{1}{K_d} - \left(1 - \frac{1}{K_d}\right)\frac{1}{K_d}$$

and likewise in the third time cycle.

By repetition of this process the distribution of activity up to 1000 time cycles has been calculated and the result is shown in Fig. 1 for c = 1, 10, 100, 500 and 1000. These curves have been calculated so that they may

be applied to a real case by letting one time cycle equal the time to flow one unit distance, and the length of zone be equal to $100/K_d$ units distance. Thus for an aquifer flowing at ten feet per day one time cycle would be 1/10 of one day. The length of zone for Sr^{90} in montmorillonite would be 100/2470 = 0.0405 feet, using the value of K_d from Table I. In this example after 100 days the distribution will be given by the curve for c = 1000 (ten cycles per day times 100 days) and the distance covered by the average or peak of the distribution will be 10 zones or 10 times 0.0405 feet = 0.405 feet, but 10% of the activity will have travelled 18 or 19 zones or 0.73 feet. The concentration in the peak zone, however, is only 12% as large as it was before the flow began to spread the activity and after many thousands of cycles the radioactivity will be dispersed so that its concentration at any point is a few orders of magnitude lower than when it started. The inherent nature of the ion-exchange process serves to distribute the radioactivity over larger and larger areas and reduce the contamination level. This calculation does not take into account the lateral diffusion of the ions which would further disperse the radioactivity, and assumes completely laminar flow.

The result of a calculation using equation (4) may be checked against the results using Fig. 1. Using the same example of Sr^{90},

$$F_a = \frac{10}{1 + 2470} = 4.05 \times 10^{-3} \text{ feet per day}$$

and after 100 days the average distance travelled is 0.405 feet which was also calculated from the curve in Fig. 1.

The fraction of the initial radioactivity in any zone (n) after any number of time cycles (c) may be calculated from the expression

$$A_n^c = \left(1 - \frac{1}{K_d}\right)^{c-n} X \left(\frac{1}{K_d}\right)^{n-1} X \binom{c-1}{n-1} \text{(reference 16)} \qquad (8)$$

where $\binom{c-1}{n-1}$ is the binomial coefficient of c-1 and n-1 and is equal to

$$\frac{(c-1)!}{[(c-n-2)!\,(n-1)!]}$$

however this expression is cumbersome to calculate for large values of c and n. The curve for c = 10,000 in Fig. 1 was calculated from this equation.

It should be noted that the studies done at Hanford[10, 11, 12, 13] with

flowing columns should not be expected to fit these calculations because the Hanford studies were performed in such a way that additional activity was introduced into the soil continuously until the soil was saturated, while the calculation here assumes that after flow starts, no activity is introduced.

In summary it may be said that the ion-exchange behavior of the major fission product radioactivities is well understood, and that their behavior serves to essentially eliminate the potential hazard from ground water contamination with debris produced by an underground nuclear explosion. This results from the restriction of movement of cationic fission products to generally less than one percent of the water flow and from their gradual dispersion over large areas so that future withdrawals from the contaminated aquifer region could never contact more than a very small portion of the total activity.

Table I. Capacities and Distribution Coefficients for Several Radioactive Ions on Several Kinds of Soils and Minerals in Water.

Material*	Capacity meq./100 g.	K_d-Distribution Coefficients Cs	Sr	Y	Pu	Ce	Ru	Reference
1.	--	> 90	> 90	> 90				15
2.	18.3	100,000	576	8,270		50,000	505	9
3.	8.2	4,490	416	2,890		12,500	97	9, 10, 11, 12
4.	14.6	4,490	645	4,950		5,510	112	9
5.	17.4	3,530	221	16,600		12,500	166	9
6.	6.0	4,490	35	408		545	92	9
7.	15.1	4,110	505	12,500		12,500	120	9
8.	14.3	100,000	666	7,100		50,000	273	9
9.	68.2	16,600	259	5,510		12,500	172	9
10.	--	7,590	2470	33,200	50,000	49,900	1560	6, 9, 13
11.	--	1,290	233	49,900	550	200,000	1560	6, 9, 13
12.	2				150			6
13.					171			6
14.	1				82			6, 13
15.					4,900			6, 13
16.	Average K_d for mixed 1-year old fission products: 370							

*See next page.

Description of soils and minerals in Table I:

1. Mixed surface organic and inorganic "red" soils from Savannah River.
2. Aiken clay loam (kaolinite) pH 5.7, 4% organic, exchangeable ions Ca and Mg.
3. Hanford composite soil (primarily illitic) pH 6.6, 1.45% organic, exchangeable ion Ca.
4. Nevada sandy loam pH 8.6, 0.52% organic, exchangeable ions Ca and Na.
5. Panoche clay loam (< 21μ particles) pH 7.7, 0.47% organic, principal exchangeable ions Na and Ca.
6. Sassafras sandy loam (kaolinite) pH 4.6, 1.58% organic, principal exchangeable ions, Na and Ca.
7. Sorrento fine (kaolinite with montmorillonite) pH 8.0, 1.52% organic, principal exchangeable ion is Ca.
8. Vina fine (montmorillonite with kaolinite), pH 6.5, 0.48% organic, principal exchangeable ions are K and Ca.
9. Egbert muck pH 3.9, 32-35% organic, principal exchangeable ion is Ca.
10. Pure Colorado bentonite (montmorillonite) pH 8.2, < 21μ size, principal exchangeable ions are Na and Ca.
11. Kaolinite, < 21μ, pH 4.3, principal exchangeable ions are Na, Ca and Mg.
12. Chalk River "soil", 80% sand of quartz, feldspar, and hornblende; 2% clay of illite type.
13. Separated feldspar 2 to 0.2 μ size.
14. Separated quartz 2 to 0.2 μ size.
15. Separated Glauconite (illitic mineral) 2 to 0.2 μ size.
16. Meteoric dust and rhyolite roofing granules. Not separated for particle size but all less than 1 mm.

III. THE OCCURRENCE AND FLOW OF UNDERGROUND WATER

This section contains a brief description of the nature of aquifers and has been largely summarized from Tolman[7] and Meinzer.[17]

A. Occurrence and Nature of Aquifers

Ground water occurs in three different types of aquifers. These are water table aquifers, confined water aquifers (artesian or pressure systems) and solution channel or fissure aquifers. The first two are by far the most important water sources for commercial and domestic use since they are easiest to encounter in drilling, but there are areas where the only ground water which exists occurs in fissure and solution channels of the third type.

Water table aquifers consist of porous materials generally of the alluvial type where some classification of particle size has occurred. A water table aquifer is characterized by being in more or less direct pressure contact with the soil surfaces so that the level of water is fixed by the quantity of water and available void space. Void spaces in this kind of aquifer cannot exceed about 40% of the total volume and are generally about 20% or less. The profile of the water table is in general a subdued replica of the surface profile. That is, the distance from the ground surface to the water table does not change as much as would be expected from surface feature variations assuming a flat water table. The depth to the water table on the top of a hill might be only slightly more than the depth in an adjacent valley.

Confined aquifers are like water table aquifers in that they consist of the same kinds of materials but differ in the fact that their upper surfaces are bounded by impermeable beds (for instance fine clay) so that their physical limits are not determined by the available volume of water but by the available space. Since the permeable water-containing strata are generally not level, pressure gradients are developed from point to point by gravity, and a spatial representation of the pressure in a confined aquifer is called a pressure surface. When the pressure surface is higher than the ground surface, artesian flow occurs when the aquifer is penetrated.

Perched water tables are like confined water systems except that the impermeable beds prevent the water from freely flowing at the bottom and sides instead of the top. In this way an ancient stream bed of permeable gravel surrounded by impermeable silt might produce a perched water table

separated by many feet from the general water table in the same area. All of the available connected pores will be filled with water below the water table even though not all strata can be considered aquifers. The aquifer must also be permeable.

Solution channel and fissure water systems develop in slightly soluble rocks along fissures and bedding planes. Most water which is encountered below "bedrock" and in carbonate rocks exists in this kind of aquifer. The primary difference between fissure water and water table or confined aquifer water is that the local direction of flow is determined primarily by the structure of the fissure, and there may be little or even no exchange between relatively close lying fissures. Fissure aquifers in general are not necessarily filled with porous conglomerate so that ion exchange takes place on exposed surfaces rather than throughout the aquifer volume. Flow rates in the channels may be very much larger than through alluvial or conglomerate materials.

B. Source and Quantity of Ground Water

Ground water derives from two primarily different sources. The most important source is from rainfall. The path from surface runoff to a particular aquifer may involve transfer through a stream bed, but lakes and streams ultimately derive all their water from rainfall also. The other source of water is from mineral decomposition. Water is an essential part of the structure of most earth minerals, and heating or pressurizing them causes physical and chemical changes which may involve the release or uptake of water. It is probable that all the water presently on the earth's surface originally came from this source during the formation of the earth. It is improbable that much water is presently leaving or entering the total free water inventory from rock decomposition.

Water does not exchange between the earth and atmosphere or ocean rapidly. It is estimated that at any time about 0.1% of all free non-saline water is atmospheric, 1.5% is on the surface in lakes, streams, inland seas, etc., while about 45% is in the ground within 2500 feet of the surface and the remainder is between 2500 and 12,500 feet below the surface. (Water below 12,500 feet is not included in the estimate as "free" water and may only exist in rock solutions.) It is also estimated that about 1% of the total free water

"exchanges" per year. This is, 1% of the total "free" water is transferred from oceans into the ground water supply, and about 1% leaves fresh water storage and returns to the oceans.[18]

C. The Flow of Ground Water

Only a part of the water contained in aquifers is free to flow. Part is held by the surfaces of the mineral particles, and in fine clay which contains as much as 30% water, none may be removed by centrifuging at 1000 g. On the other hand, coarse gravel will release nearly all of the water it contains. The quantity of water a given volume of a particular aquifer material will release is termed its "specific yield", and the quantity it retains, its "specific retention".

In general the flow of water in an aquifer is determined by Darcy's law which is stated as

$$v = P \frac{h}{l} \tag{9}$$

where v is velocity, h is the hydrostatic head, l is the distance of flow and P is the constant of permeability. This constant is related to the specific retention noted above. The usual units of h and l are feet and miles while v is expressed in feet per day.

The constant of permeability determines the flow of water and is primarily a product of two factors.

The first factor which affects the permeability is particle size. The finer the particles of an aquifer material, the slower the flow of water under a given hydraulic gradient. Tolman (ref. 7a, p. 219, 220 and 387) indicates that under a 1% hydraulic gradient ($h/l = 0.01$ in equation 9) water will flow 0.001 feet per day in clay whose average particle size is a few microns, and 110 feet per day in coarse gravel whose average particle size is several mm.

The second factor which affects the permeability constant is the particle classification or porosity. If an aquifer consists of spherical particles of equal sizes, the porosity has been shown to be equal to between 0.26 and about 0.48 depending on the symmetry of packing (see discussion on p. 103 ff, ref. 7a). The permeability of such a material is ideal and quite high. If, however, smaller or irregularly shaped particles are also present they may move into the openings between the major matrix particles and markedly

reduce the permeability and porosity. In nature there is always some variation in particle size, but the variation is small in good aquifers.

Of course some aquifers existing in solution channels and fissures are restricted only by their "orifice" dimensions, and the flow-determining size may exist only in a few places over the length of the aquifers.

In nature the largest underground flow rate yet observed is 212 feet per day, and the slowest is below one foot per year. "In recognized water-bearing formations from which wells obtain their water supplies, the natural rate of movement of ground water is generally not greater than 5 feet per day nor less than 5 feet a year."[17] An average flow rate would be about 50 feet per year.

D. Relationship Between the Occurrence and Flow of Ground Water and Hazards From Radioactive Contamination.

As water moves in an aquifer, only that fraction which is determined from the specific yield measurement is in motion while the remainder is loosely bound to the solid particles. From time to time the water on the surfaces, or the bound water, freely exchanges with the free or mobile water. The effect of this exchange is to cause dissolved radioactivities to become more and more disperse as transfer continues. In fact the same equations of flow dispersion, which were stated in Section II, apply to this dispersion. The value of K_d in this case is the ratio of specific retention to specific yield and can vary all the way from zero to infinity. Values of 1 or 2 would not be unusual in aquifers from which water is obtained and the flow of completely neutral chemical species (such as tritiated water for example) would be one-half or one-third as large as the flow of water. While this concept is difficult to accept on face value, it is easier to understand if the water is thought of as if it consisted of discrete particles. A restriction is placed on the particles such that at any one time only a given fraction of them are allowed to move and all the rest must stand still. Then if a small volume of aquifer material is represented by a box containing these discrete particles and the flow is represented by addition and subtraction of particles, it is not hard to imagine a specific particle being introduced into the box and staying there for some time while new particles are placed into and then withdrawn from the box.

Since ground water generally moves a few hundred feet per year or less, hazards from short-lived fission products are practically nonexistent. Radioactivities which decay with half lives shorter than one year would generally not leave an explosion control area even if they were not adsorbed by the minerals of the aquifer, so that studies of adsorption may well be restricted to the longer-lived fission products.

Production of shattered, irregular shaped, finely divided debris, such as that described in Section I, will produce a condition in which permeability is very low by aquifer standards since all these factors act to reduce the permeability constant in equation (9). This will be especially true if most of the water transfer is in fissures or solution channels which may be easily clogged with debris or closed by the pressure produced by nuclear explosions. In this way the radioactive debris should be left in a ground water "island" even when the explosion site is an active aquifer.

It may be concluded then that under most conditions, the nature of ground water flow will aid in containing and diluting radioactivity produced by underground nuclear explosions.

CONCLUSION

There are three major conclusions which can be drawn from the foregoing discussion.

The first is that the absence of water contamination from the underground explosions in Nevada should have been expected because of the formation of insoluble glasses, the ion-exchange property of the tuff and the nature of water flow in finely divided materials. Expressed in percentages, the insolubility accounts for removing about 90% from availability, ion exchange removes more than 99% of the remaining 10% or 9.9% for every zone of thickness traversed away from the contaminated area, and the water distribution probably removes 60% of the remaining 0.1% for each zone traversed. In short, within a few feet all of the radioactivity is adsorbed in the mineral.

The second conclusion is that the principles discussed in connection with the restriction of flow of radioactivity in tuff apply to all earth minerals. Certainly many minerals when fused will not form such insoluble glasses as the high-silica, low-sodium-containing tuff, but the restrictions due to ion exchange and water division are more important in containing radioactivities

and apply to all minerals so far investigated. This implies also that studies of ion-exchange distribution constants should be extended to as many soils and minerals as possible. Data is especially sparse for high-carbonate minerals such as marble, dolomite, calcite, and magnesite. It is safe to say that sufficient data exists so that no hazard would be expected in water of average composition flowing in any mineral.

The third conclusion is that studies of the ground water situation should be made as part of every pre-explosion investigation. These studies should include measurements of the local flow rate, flow direction if there is a withdrawal point within a mile or two of the proposed explosion site, and ion-exchange distribution coefficients in the aquifer materials and local ground water. These distribution coefficients should be measured with all of the long-lived fission products, especially strontium and ruthenium. A calculation of the flow rate and dispersal factors should then be included as part of the general operational plan for each new explosion. Of course, it may be established by these pre-experiment measurements that there are no active aquifers in the area so that flow calculations will be unnecessary. After more experience in several media, sufficient data should exist to propertly evaluate the behavior with less extensive pre-explosion measurements.

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	Title
UCRL-5026	Non-Military Uses of Nuclear Explosions
UCRL-5124 Rev. I	Phenomenology of Contained Nuclear Explosions
UCRL-5253	Industrial uses of Nuclear Explosives
UCRL-5257 Rev.	Peaceful Uses of Fusion
UCRL-5281	Temperatures and Pressures Associated with the Cavity Produced by the Rainier Event.
UCRL-5457	Large Scale Excavation with Nuclear Explosives
UCRL-5458	Mineral Resource Development by the Use of Nuclear Explosives

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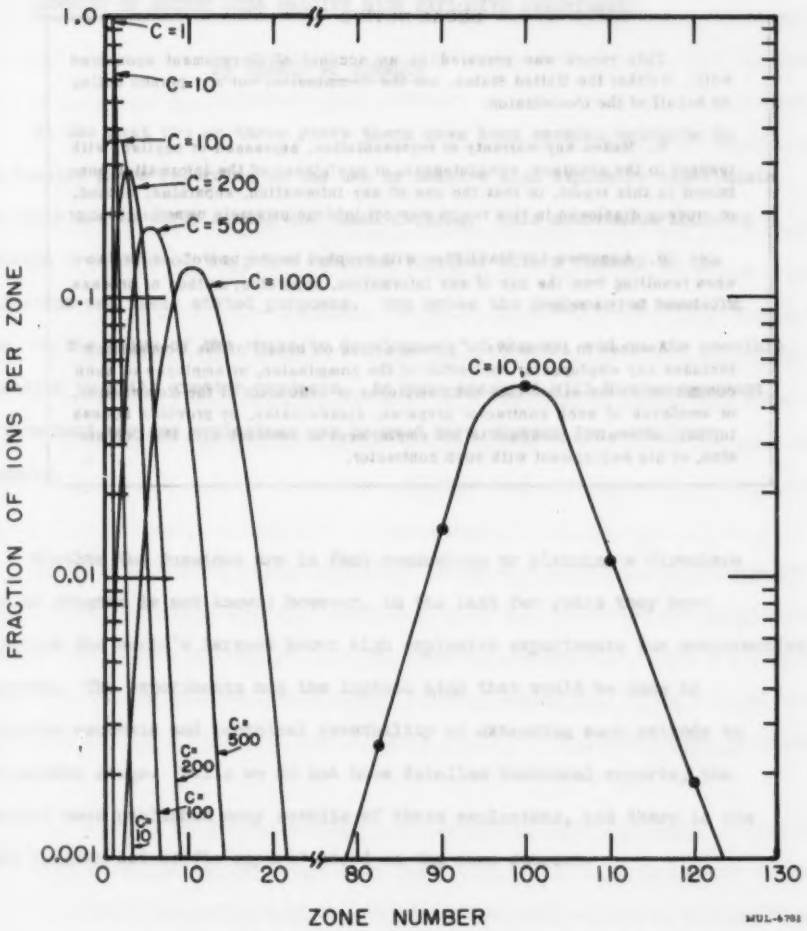

Fig. 1. Distribution of exchangeable ions after varying numbers of exchange contact cycles (c).

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SUMMARY OF RECENT USSR MASSIVE HIGH EXPLOSIVE EXPERIMENTS

by GERALD W. JOHNSON

In the past two or three years there have been several accounts in the Russian press referring to the use of massive high explosive experiments and their use in strip mining and canal digging. This memorandum includes extracts from some of the press releases together with a summary of the explosions and their stated purposes. One notes the emphasis on peaceful uses, on the value of the shots to development of theory, and on the possible extension to still greater projects. At some stage it will become apparent to them that nuclear explosives can be used more cheaply for such large projects.

Whether the Russians are in fact conducting or planning a Plowshare type of program is not known; however, in the last few years they have conducted the world's largest known high explosive experiments for constructive purposes. The experiments are the logical kind that would be done to determine economic and technical feasibility of extending such methods to the nuclear range. While we do not have detailed technical reports, the Russians have published many results of these explosions, and there is one known Belgian scientific report* based on the same sources.

We have a Moscow release dated June 13, 1958, which stated the following: "Moscow - For the purpose of scientific research, the Soviet Union recently (December 1957) conducted in the vicinity of Tashkent, the capital of the Uzbeck SSR, a successful testing of large-scale

*"Some of this information was reported in 'Projet d'explosions en Belgique', A. Wery. Communications of the Royal Belgian Observatory No. 145, Geophysical Series No. 48, dated 1958".

blasting that was unprecedented in the world. Test results proved that the force of large-scale blasting can be utilized for the construction of canals, ditches, trenches, and reservoirs, in accordance with plans formulated in advance.

"During the above blasting, the some 1,000 tons of explosive, buried under the ground in advance, blasted in a few seconds several hundred thousand cubic meters of earth, which was scattered to an area of 1 kilometer around the blasting area, and at the same time created a large hole measuring 180 meters in diameter and 42 meters in depth. The size and depth of the hole that was made by the carefully-calculated and accurate blasting were just what the scientists wanted.

"The Soviet paper (name of the paper indistinct) when commenting recently on the result of this large-scale blasting, said that by using this method of blasting, persons in charge of blastings will soon be able to lift an entire mountain into the sky, converting mountains into plains.

"A Soviet scientific organization is now preparing to use the above method to conduct large-scale underwater blasting in the Angara River in Siberia to widen the river bed of the Angara River, thus shortening the construction time of the reservoir project from five to three years. Scientists estimate that 30,000 tons of explosive will be necessary for this underwater blasting."

The cratering experiment at 1,000 tons of high explosive is larger than

any that have been conducted anywhere else. It was apparently well designed and well instrumented. The largest cratering experiments in the United States were with 160 tons.

The results of this explosion, although the details of placement of the charge or the nature of the medium are not available, give crater dimensions about twice as large as would be expected for a dry medium.

Based on other experiments and theory, the Russians have concluded that the scaling laws relating diameters and depths of craters to charge size lead to a dependence of such dimensions in proportion to the energy release to the 1/3.5 power, to use the Russian example. "In the transition from a crater with a 20-meter radius and a 10-meter depth to an open-cut mine with a 200-meter radius and a 100-meter depth, the charge has to increase....3,160 times." Using the empirical law derived in the U. S. ($W^{1/3.4}$) the charge increase would be 2,500 times, so the difference is not great. Incidentally, to produce the crater of the dimensions quoted in the Russian example would require about one hundred kilotons which is clearly in the nuclear range.

The Russians have taken the world leadership in applying massive explosions to industrial purposes. The use of explosives to displace material as contrasted with their use to crack or shatter material has been named "Diffusion Blasting" by them. Diffusion blasting is the same method of excavation that has been envisaged in the Plowshare project. Quoting again from a Russian paper "Diffusion Blasting" by Professor G. E. Pokrovskiy, The Military Aeronautical Engineering Academy (Moscow) dated August 1957.

"As is known, blasting has been widely used in mining and in construction. At present, so-called large-scale diffusion blasting has been often applied.

"The significance of this kind of blasting lies in the following: One of the most progressive and profitable ways of extracting minerals is by open-cut mining of deposits in the corresponding working faces. The work in an open-cut mine is convenient because heavy machinery, railroad and other means of transport can be introduced into it, and any blasting operations can be carried on safely. The working conditions for men in open-cut mines, as a rule, are much better than underground.

"However, in order to establish an open-cut mine it usually is necessary to remove the previously crushed overburden blanketing the coal beds or ore bodies. For this purpose multiple small-scale blastings can be used, but this would require much time for separating, loading, and hauling of crushed rock. From the organization point of view it is much quicker and simpler to use one or several very large charges not only for demolition purposes but also for the diffusion of the overburden beyond the bounds of the future open-cut mine.....

"This study permits to conclude that from power and physico-technical points of view, blastings with large-scale charges are profitable and effective, This approach forms the basis for very large-scale diffusion blastings.

"In China in recent years large open-cut mines have been developed

very effectively with the aid of blastings. Blastings have been performed there under the guidance of Soviet specialists. Scientific analysis and the preparation of plans for large-scale blastings on the inititative of M. M. Dokuchayev, the chief engineer of the 'Soyusvaryvprom' (All-Union Industrial Blasting) Trust have to be noted.

"The greatest blasting, ever carried out for peaceful purposes, took place in 1956 in the Ian'chzhou area. A massive batch of blasting charges, weighing 1,640 tons, were detonated 19 July, 4,780 tons - 16 November, and 9,200 tons - 31 December. These figures approach the trinitrotoluene equivalents of a series of atomic explosions. In the last case (the 31 December 1956 blasting) the depth for laying explosion charges was about 60 m."

In vieving the dust cloud produced by the 9,200 ton explosion of December 31, 1956, Pokrovskiy had this to say, "A moment after the fall of ejected overburden. Dense and comparatively dark masses of dust clouds caused by the falling overburden are visible. Unfortunately, this dust is a great drawback and apparently unavoidable during large-scale blastings. It is carried away by the wind for many kilometers and causes damage to plants and populated places. Dust also is the reason for difficulties in using atomic explosions for peaceful purposes, as it becomes contaminated by radioactivity and may carry radioactive substances harmful to men and animals for tens and even hundreds of kilometers.

"Apart from the direct benefits to the mining industry in China, so rich

in mineral resources, these blastings also proved to be of great value in the development of the theory of explosions. They justified the methods of computation and corroborated the opinions on the peculiarities of large-scale ground explosions advocated by Soviet scientists. However, not all phases of the explosion science have been sufficiently well studied. More attention should be paid to the study of seismic, electrical and meteorological programs in carrying out further blastings."

Other explosions for industrial purposes are described in the Russian press. From Pravda, March 26, 1958,

"Sverouralsk, Sverdlovsk Province- The largest rock clearing explosion in the history of the Soviet Union was set off March 25 near the workers' settlement of Pokrovsk Uralsky. The explosive charge weighed 3,100 tons..... In a few seconds the explosion accomplished a vast amount of work. It carved an outlet canal for the Kolonga River 1,150 meters long, as wide as 100 meters at the top and 25 meters deep. About 750,000 cubic meters of earth and rock were blasted out.

"Why was this explosion set off? The Kolonga River flows over rich deposits of iron ore. Ore-filled trains constantly ply between the river and the Serov Metallurgical Combine. However, there is a grave flooding problem in the mines, making the ore difficult to extract. The May Day Mine, which was built in 1957 has yet to be put into operation because of the great flow of water.

"So, the Pokrovsk miners, together with the Urals Explosives Trust, decided to set off three powerful blasts in order to open up a two-kilometer outlet canal for the Kolonga River. The first and second explosions, which were set off in April and December, 1957, made a cut 798 meters long for the Canal.

"The third explosion, the March 25 one, was prepared with particular care. Engineer A. Smirnov, who drew up the project, and the others in charge of the work planned and carried out the blast on a high

technical level. The explosion was detonated only one and one-half to two kilometers from the workers' settlement, but the settlement's buildings suffered no damage at all. The explosion was so cleanly carried out that no finishing work is needed on the canal. In a few months the Kolonga'a waters will be closed off by a dam and will flow through the craggy hills and into Lake Troitskeye."

In summary the available information on the Russian experiments is as follows:

TAGANSAY - Purpose was experimental but crater will be used as water reservoir.

Date	Charge Kilotons	Depth of Burst (DOB) Feet	Crater Dimensions		
			Depth (D) Feet	Radius (R) Feet	Volume (V) Yd^3
12/19/57	1.0	133	140	300	740,000

IAN'CHOU AREA CHINA - Purpose - Overburden removal.

Date	Charge Kilotons	Depth Feet	
7/19/56	1.640	?	Details on placement of charge, nature of medium, and technical results are not yet available.
11/16/56	4.78	?	
12/31/56	9.2	200	

SVERDLOVSK(KOLONGA RIVER) - Purpose - Divert Kolonga River from rich iron ore deposits.

Date	Charge Kilotons	Charge Placement (not specified)
3/25/58	3.10	Cut a trench - 1150 meters long, 100 meters wide at top, and 25 meters deep. 750,000 cubic meters of earth removed. (This gives 320,000 yds^3/kt).
4/57	?	
12/57	?	

SIBERIA (ANGARA RIVER) - Proposed 1959

Large scale underwater blasting of the river to widen the bed for a reservoir project. Planning a 30 kt explosion. Details of proposed placement unknown.

Because the results of these experiments and projects are of fundamental interest to Plowshare, the Soviet Union could make a major contribution to peaceful applications and science if it would provide the United States and the world with all technical data from these important explosions. Specifically, information is needed on the details of placement and distribution of charge, the kind of explosives used, the manner of firing, the nature of the medium, engineering surveys of the craters, the close-in ground-motion measurements and seismic observations.

It would be helpful also if United States observation were permitted of the planned 30-kiloton event both pre- and post-shot and were invited to visit the sites of the earlier explosions.

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APPENDIX V

"(Text) Novosibirsk -- A council for the use of explosions in the national economy has been set up under the Siberian Branch of the USSR Academy of Sciences, today's Vechernyy Novosibirsk reports.

"The Siberian scientists propose to strip a 45-meter thick coal seam at the recently discovered south Yakutian coking coal deposit with the help of two big explosions -- 40,000 tons of ammonal each. The seam lies at depths of 40 - 60 meters under a layer of soft sand. This tremendous explosion can also yield valuable information on the geological structure of this part of Siberia. The cost of explosion stripping will be several times smaller than the usual methods.

"The scientists also propose to build a dam with the help of explosives in the Malaya Alma-Atinka River Gorge in Kazakhstan, a few kilometers above the Medeo Mountain Skating Rink. This dam will shield the Republican capital of Alma Ata from the destructive mud and rock streams which rush down from the mountains approximately once every 50 years.

The dam is to be almost 100 meters high. It will be built by blasting the gorge sides, which will require the simultaneous detonation of approximately 5000 tons of explosives. To raise the dam to the projected mark, it is necessary to make two smaller explosions.

Explosion methods, the article continues, open up great prospects for the deepening of river beds. The volume of these works on the Siberian rivers alone will amount to many hundred of thousands of cubic meters in the current seven-year-plan period, 1959 - 1965.

The scientists have advanced a new theory of destroying the ice on waterways with the help of explosions. They have also developed a unit for drilling shot holes in hard rock with a large number of continuous blasts. A special fluid is used as an explosive."

The CHAIRMAN. Mr. Carey H. Brown, of the American Society of Civil Engineers.

Senator Moss (presiding). You may proceed, Mr. Brown.

STATEMENT OF CAREY H. BROWN, CHAIRMAN, AMERICAN SOCIETY OF CIVIL ENGINEERS LIAISON COMMITTEE

Mr. BROWN. My name is Carey H. Brown. I am here as a member of the American Society of Civil Engineers and chairman of that society's liaison committee on EJC national water policy to support the views of Engineers Joint Council on the subject, which is the concern of the select committee.

I may say this parenthetically, that closing of the Rochester Airport by fog on Monday prevented me from being here with Dr. Geyer, who appeared for the Engineers' Joint Council. Because my testimony fits in with his, and I would have liked to have been here at the same time so we might have testified together; but, due to circumstances which I could not control, I could not make it here, Senator.

Senator MOSS. We are glad you are here with us today.

Mr. BROWN. So it may be that some of the things that I am going to say have already been said by Dr. Geyer, but I hope that you will pardon that, in view of the circumstances. But the very fact that they do coincide, serves to point out that the official position of the American Society of Civil Engineers coincides with that of Engineers Joint Council, which, in fact, the American Society of Civil Engineers assisted in formulating.

The Engineers Joint Council is an assembly of engineering societies which serves as a common meeting place for the authorized representatives of those societies and as a means for united expression of views in respect to the common problems of the various branches of the engineering profession.

The combined membership of the constituent societies of Engineers Joint Council is approximately 300,000, distributed among 21 societies, each of which represents some segment of the engineering profession.

Engineers Joint Council is vitally interested in the matter of national water policy from two points of view. First, because of the active participation of engineers in water projects of all types; and, secondly, in view of the inclusion, among the objectives of EJC, of the development of recommendations regarding public policies in those areas where the application of the art and science of engineering will contribute to the general welfare of mankind.

In 1950, some 75 engineers from all branches of engineering, working under the auspices of Engineers Joint Council, prepared a report, "Principles of a Sound National Water Policy." The purpose of this report was to provide an expression of the views of the engineering profession for consideration by the then existing President's Water Resources Policy Commission. Planning and operation of the physical aspects of water resources projects, and consideration of their economic aspects as the basis for their justification, are engineering functions.

Thus a group of engineers of wide experience in water development was able to bring an extensive body of technical skill and knowledge to the undertaking. Their report was published in 1951.

Since that date several governmental commissions—the President's Water Resources Policy Commission, Commission on Intergovernmental Relations, Materials Policy Commission, Second Hoover Commission, and the Presidential Advisory Committee of 1955—have reviewed phases of water policy. Water policy has been the subject of bills introduced in the Congress, and of comments by many individuals and nongovernmental organizations. Continued activity in water resource development has also supplied additional experience during the years that have passed.

It therefore seemed appropriate that the 1950–51 statement of Engineers Joint Council be reviewed, in the light of any newer facts and opinions, and that a succinct restatement of policy be formulated.

Accordingly, a board of review was appointed by Engineers Joint Council in November 1955, resulting in the preparation of an EJC report, published under the title "1957 Restatement of the Principles of a Sound National Water Policy." This report, in its entirety, is recommended for your consideration.

I understand that Dr. Geyer, speaking for Engineers Joint Council, has requested that it be made a part of your record. I have a copy here today and Mr. Schad has suggested that I leave this, inasmuch as Dr. Geyer did not have any extra copies with him the other day.

Senator Moss. Thank you, sir.

Mr. Brown. The following brief statement, based upon that 1957 restatement, is submitted for the purpose of drawing attention to its main findings and conclusions.

The general principles are as follows:

It is essential to our coutry's economic growth and well-being that our great national water resources be developed in accordance with sound policies. The participation of State, interstate, local, and private agencies in this development should be actively encouraged and expanded, with the Federal Government assuming responsibility within its constitutional power and when its participation is necessary to serve the national interests.

It is customary to consider water resources as renewable, and, therefore, inexhaustible, but the physical sites at which these resources can be developed are limited in number. Planning must therefore be long range if proper use of water resources is to be accomplished.

The possible expenditures for water resource development are enormous, but the labor, material, and money available at any particular time for construction of such works are limited. It is important, therefore, to devote the available labor, material, and money to those projects which will make the maximum contribution of benefits, rather than to those that are merely feasible.

Reports on a project should clearly state the short- and long-range effects of the project and accurately summarize the expected costs and benefits.

Intangible or indirect benefits may influence the final decision but, in any case, they should be presented against a scrupulously accurate background of direct and tangible facts and of intangible and indirect costs and losses.

The planning of water resources project should fully recognize the roles of both surface and groundwater supply and the importance of planning land use jointly with water use.

Because there are now inconsistencies in national water policies; because the present policies of various Federal agencies should be better coordinated; because there should be greater coordination of Federal and State functions, interests, authority, and rights; because the demands of water resource development, in terms of money, labor, and material, are of tremendous magnitude, and because there is need for continued comprehensive development of water resources, there is definite need for a unified national water policy. It would, however, be contrary to the Nation's interests to force all water projects into a rigid and inflexible framework. A sound water resources policy should embody some flexibility and adaptability of methods and purpose.

Development of water resources must keep pace with national and regional needs, but should not be undertaken except on the basis of adequate and reliable basic data.

The collection and development of such data is a Federal-State-local responsibility.

Projects, within a single river basin, Federal, State, local and private, should be coordinated to provide maximum effectiveness.

The States should be encouraged to establish State water resource planning boards, to represent State and local interests in planning water projects, both Federal and local.

It is recognized that the Federal Government has a significant role to play in the development of water resources. In its exercise of that role, the Federal Government should assume the initiative in development, if and when:

(1) An economically justified project is of such magnitude as to be beyond the means of local groups;

(2) Such a project is so complex that no clearly defined local group or groups can be identified as principal beneficiaries; or

(3) The participation of the Federal Government is necessary to assure the maximum development consonant with a comprehensive regional and basin plan.

As to other projects, State, interstate, local, and private interests or agencies, should be encouraged to undertake them when consistent with a reasonable comprehensive plan.

The development, ownership, operation, and maintenance of water resource projects should be kept as closely as possible to those who use and benefit from them.

The following comments are offered as to economic justification:

1. The Federal Government should undertake projects only when they will increase the wealth of the Nation. As a measure of the direct economic effects of a proposed project, the ratio of annual benefits or values to annual costs should be computed, using direct tangible benefits and costs expressed in monetary terms.

Without an excess of benefits over costs, there can be no increase in the national wealth.

For this reason, and since the national good requires construction of the best projects first, the benefit-to-cost ratio substantially greater than 1 should be required.

If, however, intangible benefits are shown to be large and certain, authorization of an occasional project with a direct benefit-to-cost ratio less than 1 may be justified.

2. The costs reported for a proposed Federal project should be detailed and thoroughly inclusive. All items of first costs, including costs of investigation, lands, and rights-of-way, construction, interest during construction, and the cost of any measures needed to correct detrimental results of the project should be presented.

The costs of all components of the project required to achieve its intended purpose, including costs to others than the Federal Government, should be included in the cost summary.

The estimates of annual costs should include those for operation and maintenance, interest on the unamortized amount of first costs, proper allowance for taxes (paid or for foregone) amortization, replacements (to the extent required during the period of amortization) and contingencies.

Costs to be borne by non-Federal participants should also be included in the cost summary. Estimates should be clearly indicated as such and, where of doubtful accuracy, should include the maximum and minimum of the range of the cost estimates.

3. In calculating the annual cost of the project, amortization should be assumed to take place within the useful life of the project or within a maximum of 50 years, whichever is less.

4. The money rates used for calculation of project costs should cover all costs of securing money for the project.

5. The expected benefits of water resource projects should be itemized in detail and expressed in average annual monetary terms. All direct benefits, including those to be received by non-Federal participants, should be included in the appraisal of a project. Secondary benefits reflecting the increases in national income resulting from the project should be considered mainly with respect to the timing of a project (such benefits may be more important during periods of low business activity) or in choosing among otherwise equivalent projects. All benefits should be estimated by the interested agencies, according to a uniform procedure, developed with the approval of a board of review.

6. Any expedient to give unsound projects the benefit of surplus values which may accrue from sound projects should be avoided. Basin accounts may be used when in accord with normal, sound, business practices.

The EJC report to which I have referred discusses pertinent points with reference to navigation, flood control, reclamation, power, recreation, fisheries and wildlife, pollution control, municipal and industrial water supply, and watershed management.

With regard to each of these, important elements of policy are outlined.

The general conclusions applicable to all are as follows:

1. Subject to the principles of economic justification set out herein, plans for the development and use of water resources should provide for maximum utilization of these resources. The objectives of such resource development should include the safeguarding of our resources against deterioration from soil erosion, wasteful forest practices, and floods, the improvement and higher utilization of these resources, to support an expanding economy and national security; assistance to regional development; expansion of all kinds of recreational opportunity to meet increasing needs; and protection of public health.

Consideration and control of the water of the United States are in the national interest, but not necessarily a function of the Federal Government. On the contrary, that which can be done by the individual should be done by him and that which requires collective action should be done at the lowest governmental level practicable.

3. Beneficiaries of Federal water resource projects should reimburse the Federal Government for their equitable shares of the project costs.

A similar statement would apply to State projects, but as this hearing is concerned particularly with Federal activities, that is the reason for use of that phrasing.

4. Project reports should be clear and forthright, presenting all costs as accurately as possible, proposed reimbursement plans, and the amount of Federal subsidy, if any.

5. All projects within a river basin should, where practicable, be coordinated within the framework of a comprehensive plan which will assure maximum effectiveness in the development of the basin.

6. There should be a board of review for the impartial analysis of all Federal water resources projects.

7. All Federal agencies engaged in water resources development should conform to the same basic policies.

The opportunity to present these views on behalf of the American Society of Civil Engineers, many of whose members are intimately engaged in the development of water resources, is greatly appreciated.

As previously stated, we recommend your consideration of the EJC report in its entirety, as this summary is necessarily inadequate to fully cover its contents.

Furthermore, we will look forward to an opportunity to study the report of the select committee when it becomes available in the hope and expectation that Engineers Joint Counsel may be of material aid in the development of a legislative program designed to insure most effective use of the Nation's water resources. Thank you.

The CHAIRMAN. Thank you, Mr. Brown.

Mr. Robert M. Paul.

STATEMENT OF ROBERT M. PAUL, EXECUTIVE SECRETARY, SPORT FISHING INSTITUTE

Mr. PAUL. Mr. Chairman, I am Robert M. Paul, executive secretary, Sport Fishing Institute, Washington, D.C. The Sport Fishing Institute is a private, nonprofit scientific and educational fish conservation organization staffed by professional conservationists. It draws its chief financial support from a broad representation of manufacturers in the outdoor recreational industries dependent directly or indirectly upon the sport fishery resources.

Our membership includes 170 manufacturers of fishing tackle, outboard boats, motors, sporting goods, and chemical, metal, paper, and petroleum products that are used in some way by the 28 million or more Americans who look regularly to sport fishing for their chief means of outdoor recreation. The institute serves as the national spokesman in fish conservation matters for a large part of the multi-billion-dollar sport fishing industry created to serve demands by sport fishermen for needed goods and services.

In addition, a large portion of the Nation's anglers look to the Sport Fishing Institute for national guidance in fish conservation matters. A large and growing number of these folk contribute funds to the institute.

We serve as technical consultants to Government and lay conservation agencies for fisheries problems. Our sole objective is a simple one. It is to improve sport fishing to the fullest extent possible through encouraging rapid development and application of sound fish conservation practices. Or, as often phrased, our objective is "to shorten the time between bites" for the average angler.

We appreciate the opportunity of appearing before your committee and discussing recreation and sport fishing. The estimates of future population and water use that have been developed by your committee have been startling to many people. At the same time, the needs for outdoor recreation, for instance as measured by the number of visits to Federal reservoirs, consistently show a greater increase than any other water use. According to Resources for the Future, Inc., the present rate of 10 percent annual increase in outdoor recreation will eventually taper off but by the year 2000 total outdoor recreation visitation will increase tenfold. Probably half of this increase will take place by 1980.

A major part of this increase will take place on water projects constructed by the Federal Government or under Federal license. It is obvious that this public need should be more reflected in Federal water development policy than in the past and that every effort should be made to develop the public recreation potential on existing, as well as future, Federal reservoirs. Your committee can do much to help achieve this objective by recognizing the public value of outdoor recreation in your report.

The Sport Fishing Institute is also concerned with the the protection and development of fish and wildlife affected by water resource development, especially the very troublesome problems of the important anadromous fisheries. For example, we would regard any further interference with the vital Salmon River salmon and steelhead stocks as disastrous. The statements your committee has already received from State fish and game agencies, particularly those in the West, and the U.S. Fish and Wildlife Service, cover this problem very well.

We were particularly impressed with the statement of William Warne, then director of the California Department of Fish and Game, which he presented to your committee in Los Angeles on October 16, 1959. We urge that your committee consider his statement carefully—particularly the so-called "bill of rights" for development of renewable natural reservoirs. This is an excellent presentation of the problem facing fish and game administrators.

The magnitude of the total problem of providing future fishing and other water recreation is hard to imagine. The numbers of anglers continues to grow. Over the decade since 1950, the number of resident license holders has increased an average of about 3.3 percent annually. Over the same period, the number of nonresident license holders has increased at the average annual rate of about 3.9 percent. In the same decade, the average annual increase in the Nation's population was about 1.7 percent—about half the increase of fishing licenseholders.

There are now an estimated 28 million anglers of all ages in the country and they catch an astounding quantity of fish. From an analysis of published reports of creel censuses we estimate the average catch in fresh water is about 2.2 pounds of fish per angler-day. In saltwater fishing it is about 4.5 pounds per day.

The 1955 national survey of fishing and hunting showed that freshwater anglers devoted at least 338.8 million man-days to recreational fishing. Saltwater anglers fished for a total of at least 58.6 million man-days. Unfortunately, there seems to be no way to estimate reasonably how many angler-days the several million youngsters under 12 who fish may add to the total. Fishermen 12 years or older, then, caught over 858 million pounds of sport fish of all kinds in nontidal waters. This is actually a conservative estimate. When we add an estimated 319 million pounds of salt water fish caught by anglers, we wind up with the astounding total of at least 1,177 million pounds of sport-caught fish. Even discounting the recreational value completely, it is obvious that sport fishing is important nationally as a food resource.

The business generated by sport fishing offers another index to its importance. Sport fishermen probably spent about $1,900 million last year to catch their fish in fresh water and $700 million to catch fish in salt water—a total of $2,600 million. This means that $2.30 was spent to catch a pound of fish.

Rather than repeat previous testimony we will confine the bulk of our remarks to a few specific points which have not been covered in previous testimony and which we feel need to be emphasized. These are—

1. The economic value of sport fishing.
2. The need for proper public access to develop the recreational potential of Federal reservoirs.
3. The feasibility of recreational use on domestic water supply reservoirs.
4. The pressing need for basic research to maintain good fishing in reservoirs.

THE NATIONAL VALUE OF SPORT FISHING

At the time Senate Resolution 48 establishing your committee was introduced in the Senate, Senator Mansfield stated:

> Still another important aspect of the water-resources problem is one equally valuable to Americans, even though we may not measure it in billions of dollars. Wildlife, and recreation are, in great measure, closely dependent on the wise conservation and development of water resources. From ducks or trout to summer resorts and swimming holes, concern with wildlife and recreation is inseparable from concern with water resources.

The intangible value of these resources cannot be questioned, but at the same time we can develop economic values to compare the benefits of recreation with the other uses of water. There are some good estimates of the dollar values of outdoor recreation that may be of interest to your committee.

The first National Survey of Fishing and Hunting was undertaken for the U.S. Fish and Wildlife Service in 1955. It is being repeated this year. The 1955 survey revealed that 21 million Americans 12

years or older fished that year. They spent almost 400 million man-days at their favorite means of outdoor recreation. They also spent over $1.9 billion for the goods and services required "out fishing" while driving 8 billion miles. This averages out to $92 per angler or about $4.82 per angler-day. Salt-water anglers spent $8.34 per day. Fresh-water anglers spent about $4.20 per day.

The number of fishing license holders have increased about 3.3 percent annually averaged out over the past decade. Using this basis of projection, it appears that total expenditures made by anglers in the pursuit of their sport have grown to more than $2.6 billion each year.

Capitalizing this annual expenditure at 4 percent, we can assume that the national sport fishery resource has a monetary value of more than $65 billion. Of course, this is a wholly inadequate measure of value since this is a perpetual natural resource. It will undoubtedly generate far greater expenditures in the years to come as the number of recreational days "out fishing" increase.

LOCAL BUSINESS GENERATED BY SPORT FISHING

It is possible from this to assign a minimum figure for the potential value of a community or a region of an acre of water used for fishing in terms of business activity it may generate. It appears that intensively managed waters are potentially capable of supporting at least 100 or more, often far more, fishing trips, angler-days) annually per acre. Full realization of this potential may be many years in the future on most waters, in many sections of the country, but this figure represents a currently attainable goal in many waters.

Generally, the most intensively fished waters are located close to large population centers—usually within 50 miles. Local anglers from these areas seldom spend as much as the national average. They seldom need commercial overnight accommodations. Some other expenditures for heavy equipment like boats, motors, and trailers may be reduced—perhaps halved—even though the latter are purchased for general use in any event. So, it seems realistic, with respect to purely local fishing activity, to reduce the average daily expenditure for needed goods and services arbitrarily by some 50 percent—to about $2.10 per day in fresh water—to account for these reductions.

On this basis it is estimated that each acre of fishing water managed intensively for warm-water fish has a potential to generate some $210 of local business activity annually. This is equivalent to a capital investment at 4 percent of $5,200 per acre of water. Present economic values may be half that much or less depending on the quality of fishing provided by limited management. This return is equivalent to a capital investment (at 4 percent) of $2,600 per acre.

This compares very favorably with the economic feasibility pattern that has been firmly established for golf courses throughout the country. Golf courses accommodate similar use levels, experiencing about 125 golfer-days (rounds) per acre of available courses. Each acre of golf course constructed in the country has required a capital investment averaging about $2,470.

Such values have been criticized with some justification as being measures of secondary rather than primary economic benefits. Economists say if anglers could not or did not spend their money on fishing, they'd spend it somewhere else, perhaps playing golf as an example. Critics contend that there is no new economic benefit created by virtue of the intrinsic values of that particular activity, be it fishing, hunting, boating, or something else.

Technical arguments of this sort miss the point in our opinion. The important fact is that over 28 million Americans of all ages deliberately choose to fish for sport, as a matter of conscious preference. In doing so, they have caused the development of a multibillion-dollar sport fishing industry to meet their demands for a variety of specialized goods and services.

Recreation is a primary benefit of water development. Past difficulties in developing sound economic measures of primary benefits from recreation have resulted in the practical exclusion of recreation from benefit-cost computations of water developments. A satisfactory measure of primary recreation benefits has been badly needed. A new approach to the problem was recently employed in California in connection with the upper Feather River development that merits close study. In that instance a basic and reasonable $2 per visitor-day of primary recreation benefits was computed and recommended for adoption.

To economists, the chief objection to use of values derived through the expenditure approach (for example, the earlier reference that U.S. sport fishermen averaged $4.82 expenditure per day out fishing in 1955) has been that many so-called recreational expenditures, in part at least, may represent normal expenditures made under slightly different circumstances. Even net recreational expenditures fail to adequately measure the intangible aspect which is recreational enjoyment. In other words, there is merit in the belief that expenditures seem to be significant measures of secondary benefits to the business community rather than measures of primary recreational benefits.

In this case, however, it was necessary to develop a valid estimate of the primary benefits of recreation. After careful analysis of various possible methods and values, it was concluded that computations based on costs of travel alone (using a fixed cost per mile of travel) offer the least objectionable method for measuring the free recreational value that represents primary benefits. In the method used for the upper Feather River project—

(1) Successive geographical zones are established around the recreational area based on distance from the area;

(2) average costs of travel from each zone to the area are multiplied by the number of potential users within the zone;

(3) costs of travel for visitors from the outermost zone set a "bulk line" value of recreation provided by the area;

(4) the free value (primary benefit) of recreation to those traveling shorter distances is determined as the difference between travel costs between successive zones and the "bulk line" value; and

(5) finally, the summation of differences between the average travel costs from each zone and the "bulk line" values multiplied by the respective number of recreationists yields the dollar measure of total intangible value of recreation.

Using this approach for reservoirs in other areas yields some interesting values. For instance, Fort Gibson Reservoir, Okla. (19,000 acres) supported 31 fishing trips per acre in 1956. Tulsa, about 40 miles distant with nearly 200,000 population, is the chief source of recreational fishing users. The calculated free recreational value (primary benefit) to Tulsans of sport fishing at Fort Gibson, applying this formula, amounted to $1.80 per visitor-day—equivalent to $55.80 per acre. Capitalizing again at an interest rate of 4 percent, each acre of water at Fort Gibson would have a capital value for sport fishing amounting to not less than $1,395.

Regardless of the method used, there seems to be no question that the Federal conservation agencies need more authority to properly plan for recreational use and the value of this use can properly be reflected in the economic evaluation of water projects in the planning stage.

Regardless of economic theory, the chief value of such figures is to place outdoor recreation in its proper perspective in water development planning. The recreation values offer strong argument for more active preimpoundment and postimpoundment fish and game management programs to meet expected recreational pressures. They are a strong justification for including in project plans such additional facilities as anticipated use may indicate are needed to accommodate the many citizens who look to water for vitally needed recreation.

THE GREATEST NEED IS PUBLIC ACCESS

Among the recreational needs that must be given immediate attention is adequate facilities for public access to water, including roads, parking and turning space, boat-launching ramps, sanitary facilities, and in many cases, picnic and campgrounds as well. Two years ago, the Sport Fishing Institute undertook a national survey of access development on public waters by State conservation or fish and game agencies. Briefly, it was found that the State conservation agencies have thus far provided one access area per 300 acres of fishing water affected. Boat-launching ramps were constructed on the ratio of 1 per 500 acres of water. At the same time, it was determined that probably less than 1 percent of needs have been met to date.

It is well established that fishing represents the chief use of boating equipment. Consequently, the States have equipped somewhat over half of the access areas with boat-launching ramps and associated facilities. The ratio of 1 access site with boat ramp per 500 acres of water probably represents a minimum for design of access facilities for new large reservoirs. In past cases, lands acquired for parking, trailer turnaround, and associated facilities have become decidedly overcrowded in very short order.

These data, taking into account probable future needs to meet anticipated growth in demand for waterborne outdoor recreation, suggested a formula for access acquisitions. It is recommended, in the absence of camping, that one access site comprising at least 10 acres of land should be acquired for each 500 acres of large lake or reservoir water area to be serviced (the smaller ratio of 1 to 300 seems more applicable to smaller bodies of water). If camping is to be permitted, at least 100 acres of land should probably be acquired per site.

It is conceivable that these goals may well prove inadequate in a few decades. The important thing would seem to be to acquire adequate lands before land prices rise from residential to industrial brackets. Initial development might involve as little as one-tenth of the areas acquired, with increasing development of holdings to meet actual levels of utilization that may occur in the future.

We hope that your committee recognizes the need for additional public access in your final report. The Corps of Engineers present program of providing adequate public access to their existing reservoirs should be encouraged and speeded up. The Corps of Engineers also needs broader authority for proper recreation planning of future projects.

The question of Federal reservoir land acquisition policy is still causing State recreational agencies considerable concern. As you know, there have been instances where the States have had to purchase land at tremendously inflated prices. The magnitude of this problem and the difficulties imposed by the land acquisition policies of the Federal agencies were pointed out very clearly by the House Government Operations Committee hearings in 1957. The committee's report of August 16, 1957, recommended changes in the policy, but their recommendations have not yet been fully augmented. The land acquisition policies of the Federal construction agencies is an excellent area for future study by your committee. The question of whether or not the Corps of Engineers has authority to recommend land acquisition for fish and wildlife under the terms of the Coordination Act needs to be resolved.

RECREATIONAL USE OF WATER SUPPLY RESERVOIRS

Another point that we wish to emphasize is that recreational use is entirely feasible even on water supply reservoirs. This is particularly important in view of the broader authority recently given the Corps of Engineers to include capacity for future domestic water supplies in current reservoir construction. Curtailment of recreational use in these instances would not be justified in our opinion. To the contrary, we should broaden our multipurpose philosophy to insure that maximum benefits are secured from existing as well as future water projects.

Full utilization of known principles of fish and game management and development of access, sanitary facilities, and recreational areas is practiced by a number of progressive water departments. Many municipalities such as Boston, New York, New Brunswick, N.J.,

Columbus, Tulsa, San Diego—to name only a few from east to west—have adopted the multiple-use approach. Some go so far as to employ professional conservationists on water department staffs to manage the waters for maximum recreational potential.

An outstanding example is that of San Diego, Calif., where full recreational use has occurred since 1931. The city's 7 reservoirs, with some 4,000 acres open to use, supported 118,600 individual fishing and hunting trips (30 per acre) in fiscal year 1955. Daily use fees of $1 per person over 16 years of age are charged.

At each station there is a consessionaire, chosen by competitive bidding, who is responsible for collecting fees and issuing permits. The concessionaire is also subject to rigid health inspection and strict control by the water department. Appropriate sanitary facilities are provided at intervals of 1,000 to 2,000 feet around the perimeters of the lake.

The overall operation is under the supervision of the water production division. A supervising recreation specialist is employed for the planning, inspection, and liaison work with the different agencies involved.

The San Diego Water Department considers water recreation to be one of the important multiple uses of a reservoir water supply. But it has never forgotten its prime purpose—that of supplying pure water. Water-treatment plants have been necessary because of turbidity, taste, and other factors not related to water recreation.

It is interesting to note that San Diego has stated that—

> through the years there has been no correlation between the bacterial count of water samples and recreational use. On numerous occasions the highest counts have been at times when no recreation activities were in operation.

Fish management activities can be most beneficial to the primary objectives of producing safe potable water. For example, treatment with rotenone removes rough fish. Its purpose is twofold: to improve sport fishing, and to improve water quality by reduction of turbidity. Both objectives were successfully accomplished at Hodges Reservoir by San Diego and this kind of fishery management is commonly practiced also by many municipalities in Oklahoma in cooperation with the State conservation department.

In another example, the quality of fishing in San Diego's San Vicente Reservoir recently deteriorated. Therefore, the San Diego Water Department engaged the fishery research staff at San Diego State College to conduct a fishery study. Basically, the study is designed to guide fishery managers toward an implemented management program for San Vicente Reservoir.

In San Diego, it is not a question whether fishing should be allowed. The only question is, how can it be made better? This is an example that every water agency can and should follow.

THE NEED FOR SPORT FISH RESEARCH AT LARGE RESERVOIRS

The problem of how to make fishing better in reservoirs is nationwide. The hearings on S. 1262 (Senator Fulbright's bill directing the Secretary of Interior to start a reservoir sport fish research pro-

gram) before the Senate Interstate and Foreign Commerce Committee earlier this session gives ample testimony to this. There is a pressing need for a broad basic research program to find out how to maintain and develop good fishing in large Federal reservoirs.

Initially, reservoir sport fishing in formerly lakeless parts of the United States has typically been phenomenal. However, catches tend to taper off to a stable (sometimes undesirably low) level as the reservoirs age. Why? What can be done to cure fishing ills and enhance potentially high fish production? Only research into the fundamental nature of the biological facts of reservoir life can solve these riddles.

The fishing bonanza often created by impoundments has been accompanied by many vexing problems in attempting to maintain or improve the fish populations. Fishery research conducted by a team of biologists employed by the Tennessee Valley Authority in the late thirties and forties has shown what must be done to find some of the answers. But, much of the basic biology on which proper management most ultimately depend remains unknown. Unlocking the secrets of reservoirs is an immediate need of the fishing public and those charged with providing good fishing.

State fish and game agencies, operating on limited budgets, are beset with a multitude of responsibilities and have been unable to attack reservoir fishery research on anywhere near an adequate scale. They are, therefore, without the facts needed to develop management techniques which will improve fishing. Lacking management, the game fish populations maintain a static low level of production, or go downhill as time passes. With fishing pressure spiraling upward, these Federal reservoirs will be unable to meet demands without improvements.

These reservoirs were built and are operating under provisions authorized by the Congress. They have inundated stream valleys throughout the country. Vast and valuable new warm-water sport fisheries have been developed in many of them where anadromous fisheries are not involved. At the same time, they have created problems in fishery management which the States have been unable to solve. In view of the Federal, and often interstate, nature of these waters a Federal program designed to attack these federally created fishery problems would be unquestionably justifiable.

Responsible officials in the Fish and Wildlife Service recognize these needs—some 35 State fish and game agencies testified to the need for a Federal reservoir sport fishery research program. The Fish and Wildlife Service, too, needs the benefits of such a program for proper discharge of its assigned legal responsibilities with respect to the effects of river impoundment. The Service must undertake river-basin studies and make authoritative recommendations affecting proposals for engineering structures and other improvements on many rivers and estuarine areas involving many millions of dollars annually. Improved knowledge would aid in strengthening this program and S. 1262 would go far toward meeting this need. We anticipate this bill

will be passed by this session of Congress—it has already passed the Senate and hearings have been held by the House Merchant Marine and Fisheries Committee.

We urge your committee to recognize this need for reservoir research in your final report and urge the Department of Interior to make an early start on the program we anticipate will be authorized by S. 1262.

OTHER IMPORTANT CONSIDERATIONS

There are a number of other points regarding recreation and fish and wildlife which have already been called to the attention of your committee which we do not believe need be repeated. The reports of the U.S. Fish and Wildlife Service and the National Park Service are particularly good and we can generally concur with their recommendations.

The report of the Public Health Service on the need for proper water quality management has important implications for recreation and fisheries that should be emphasized by your committee. As far as these uses are concerned, there is no substitute for an adequate supply of water—of good quality as well as quantity. Both the State and Federal water pollution control programs should be strengthened to meet this objective.

For your information, and to provide detailed documentation for this statement, we are attaching a copy of the Sport Fishing Institute's recently published "Fish Conservation Highlights, 1957–59." We want to call your attention, particularly, to the statistics on numbers of anglers and the current estimates of numbers of fish that are caught (pp. 2–10). Additional sections summarize fish conservation activities of State fishery expenditures for development and research (pp. 17–23), construction and rehabilitation of fishing waters (pp. 27–30), multiple use of water supplies (pp. 31–33), and Federal water development programs (pp. 38–40). Some interesting information on Canadian programs is included in the pages that follow.

Thank you very much. We appreciate the opportunity of presenting the statement and, if we could be of any assistance, be sure to call on us.

The CHAIRMAN. We thank you. We are very much interested in your organization and with you. We appreciate your being here and presenting the statement.

The National Association of Rural Electric Cooperatives and the Edison Electric Institute will provide statements which will be inserted in the record. We will also insert a report on Ground Water Recharge by a task group of the American Water Works Association.

(The statements referred to follow:)

STATEMENT OF
NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION

Mr. Chairman and Gentlemen of the Committee:

My name is Charles A. Robinson, Jr. I am the Staff Engineer of the National Rural Electric Cooperative Association; a National service organization of which some 925 REA financed rural electric systems are members.

Interest of Rural Electric Systems

Over 450 rural electric systems now purchase all or a portion of their wholesale power requirements from Federal power marketing agencies. During fiscal 1958 (the latest year for which published figures are available) they purchased 9.1 billion kwh of wholesale energy from Federal power marketing agencies to which they paid $45 million. This represented, during that year, approximately 40% of total wholesale energy input to all rural electric systems. During the same year, the rural electrics purchased a similar quantity of wholesale energy, 9.1 billion kwh, from investor owned utility companies to which they paid $72.5 million. The remaining 20% of system power requirements was obtained from local public agencies and REA financed generating plants.

These figures convincingly disclose that, on the average, our members are able to purchase from the Federal government 60% more wholesale energy per dollar spent than they are from investor owned utility companies. To these direct savings, which now amount to some $27.5 million per year, must be added the indirect benefits which arise from the competitive effect of Federal power, and which are manifest by lower rates in areas adjacent to centers of Federal power.

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Moreover, the total energy sales of rural electric systems are continuing to increase very rapidly. Figures released by REA on January 11 of this year show that between 1958 and 1959 total energy sales increased 15.5%. This means our loads are continuing to double each four to five years. Compared to the fact that the loads of the electric industry of the United States as a whole are doubling every seven to ten years, it is not difficult to understand why some of our members are experiencing difficulty in locating the supplies of energy they will require for growth in future years at rates which they can afford to pay.

The Greater National Interest

Rural electrification cannot exist, in much of the country, without continued Federal multiple purpose resource development. But of even greater importance is the dependence on Federal water resource development of the entire national economy. This is the bigger national interest. It is manifest by our growing need for water and by our growing need for power.

Just last week, in an address to the National Rivers and Harbors Congress, U. S. Surgeon General, Leroy E. Burney asserted that within 20 years the nation's fresh water needs will exceed the national supply by 85 billion gallons per day.

Washington's own Potomac River is an excellent example. It is almost 100% uncontrolled. Any repetition of the low record flow of 1930 would leave the D. C. Metropolitan area without sufficient water, and transform the river below Chain Bridge into a non-flowing ebb and wash of salt water, partially decomposed solid sewage, the soiled household detergents from the washing machines of suburbia, and liquid sewage plant effluent.

American industry recognizes that in the next 15 years our population will increase by 60 million human beings.* It recognizes that to support such a population, present water supplies must be doubled by 1975. And, from the dusty plains of the Southwest to suburban Chicago water supplies are short now. We are looking at the future from an already resource-deficient position.

Fortunately, rainfall provides more than enough water for foreseeable needs although not always at the right times or at the right places. The control and conservation of this water is a big and complicated job. It is predicted that to meet our water supply needs of 15 years hence, our country must build 123,000 new dams.*

The Chairman of this Committee has himself stated:

> "In most areas the key to adequacy of the water supply is the construction of dams and reservoirs to conserve water for release as needed for water supply, to dilute pollution, keep navigation moving, generate hydroelectric power, preserve fish and wildlife and for other purposes. These reservoirs must be planned in systems which will both regulate the flow of the streams for flood protection and at the same time conserve water for beneficial use. Few river basins as yet have anything like adequate reservoir capacity to meet growth needs."

Our need for power will parallel our need for water. Even the investor owned utilities concede this.

The Edison Electric Institute, variously referred to as a "research organization" or a "private power company front," in its report to this Committee, estimates that by 1980, the peak demand for power in the United States will exceed 500 million kw compared to 129 million kw in 1959 - a

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* - The Saturday Evening Post, April 23, 1960 - Double Spread Advertisement Sponsored by Caterpillar Tractor Company.

290% increase. Kilowatt hour sales are slated to reach 2.8 trillion by 1980 compared with 707 billion in 1959 - a similar 290% increase. And EEI is not noted for overestimating future demands for electricity.

If consumer interests are to be protected, a substantial portion of this increase must be built by the Federal government. Federal power is low in cost at the retail level when properly costed and marketed. Its competitive effect on the market is salutory.

A recent study of retail power rates conducted by NRECA shows convincingly that retail rates in cities located in major Federal wholesale power areas are 40% below those in areas remote from Federal power projects. And rates in cities close to but not actually in Federal power areas are 15% below those in cities far from Federal projects. (See Chart 1)

The picture is clear. Federal power is a competitive regulatory force essential to the protection of the public. And, Federal power is indispensable to water resource development.

Power is the Paying Partner

Low cost hydroelectric power is an incident of true multiple purpose water resource utilization. But, though low in cost to the purchaser, power is the paying partner of such projects. It pays for itself, and, in most instances, it pays the major portion of project cost allocated to irrigation.

Hydroelectric power revenue is one factor indispensable to maximum economic water resource utilization. It is the factor that unlocks the door to financial feasibility.

The logic seems clear. Without an expanded Federal water resource development program, our nation will dry up. And any such program which does not include hydroelectric features where justified, must, as the result of dollars and cents considerations, fail to achieve the full potential realizable from the identical program with power features included.

Only in the measure that hydroelectricity is considered as an integral part of our nation's water resource development program, can that program realize its full potential. Power and water are mutually inseparable and indispensable. One should not be developed without the other. Only in the light of these factors can the doctrine of "No New Starts" be intelligently evaluated.

Failure of Administration Leadership

Notwithstanding the universally recognized need to accelerate water conservation, the American people have not, during recent years, received from the Federal government the leadership in water resource development to which they are entitled.

These years of "No New Starts" have witnessed the adoption of multiple purpose project evaluation criteria designed to render such projects apparently unattractive and not worthy of Federal development. The cost allocation procedures and payout schedules applicable to such projects have been juggled to inflate the cost of Federal hydroelectric power so that in some cases it appears to cost almost as much as power produced from comparable investor financed plants. The Federal "yardstick," for which the Tennessee Valley Authority became so famous, has been carefully hidden behind a smokescreen of technical nonsense. Regulation by competition has practically disappeared.

This has been an era of unprecedented subsidy for investor owned electric utilities which have been forgiven $23-25 billion of Federal tax liability by way of accelerated and modified depreciation allowances. For seven years Administration spokesmen have actively supported before Congress bills which would afford multi-million dollar annual "headwater benefit" payments to subsidize the development of lucrative hydroelectric sites by investor owned companies.

Most subsidies benefit a particular group at the expense of all taxpayers. But this proposed "headwater benefits" subsidy would enrich investor owned utility companies, not at the expense of the general taxpayer, but at the expense of the Federal multiple purpose projects downstream from them - that is, at the expense of the purchasers of the Federal power. This is two-edged legislation which would subsidize investor owned utility companies, and, simultaneously, destroy the competitive effect of nearby Federal plants.

Something Must Be Done Quick

It is quite clear that if our nation is to meet the needs of its citizens for life alone, not to mention the demands of a tremendous military and industrial complex necessary to preserve our national security, we now face an unprecedented need for leadership in water resource development. We cannot longer afford to pursue a resource development policy designed to accommodate the dictates of private profit exclusively. There must be a yielding of monopoly to the public interest and, there must be leadership with enough authority and initiative to accomplish results. This we believe must be high level leadership in the Federal government, because the Federal government is the only entity which possesses the legal and political power to get the job done.

A Bold Resource Development Program

The general program which we propose substitutes the interest of the public for the interest of the fast buck for the privileged few.

I. We propose an immediate and effective assertion of Federal leadership in natural resource development. There must be substituted an agressive "can do" policy for the present policy which appears more anxious

to avoid competing with investor owned property rights, and imagined property rights, than to build water resource projects.

Federal leadership in resource development necessarily includes:

(a) Abandonment of present evaluation criteria designed to discourage and restrict Federal multiple purpose project construction; the principle of "taxes foregone" should be discarded; recognition should be afforded all tangible and intangible benefits in project evaluation studies; project repayment should be extended to 100 years, and interest rates applicable thereto stabilized.

(b) Reduction of present unreasonably high allocations of project costs to hydroelectric power in order to restore the "yardstick" benefit of Federal power.

(c) Rejection of piecemeal, project-by-project planning, and substitution therefor of comprehensive basinwide development providing for the full utilization of all water resources.

(d) Establishment of Federal resource development goals. The question is now not the extent to which we can develop water resources under present restrictive criteria; but, rather, how best we can meet the needs which we know will arise 15 or 20 years from now. For these needs must be met or we will not survive.

II. We propose the enactment of "Giant Power" legislation to provide a nation-wide, high voltage electric power transmission network. Such a network would replace or supplement the present system of loosely interconnected independent electric systems. Some electric power systems even

avoid interconnection with other systems lest they come under Federal Power Commission jurisdiction. A Giant Power network would interconnect major Federal water power projects with load centers, and with large efficient thermal generating facilities constructed by the Federal government, by investor owned utility companies, by rural electrics and by all other groups.

The United States has never enjoyed the economy of a unified electric system interconnected and synchronized coast to coast.

Equal opportunity should be should be afforded to all electric distribution systems, irrespective of type of enterprise, to obtain for their ultimate consumers abundant wholesale energy at the lowest possible cost.

We will not meet future needs for electricity at minimum cost unless our electric power supply systems are unified. Continuation of the interminable fight by investor owned utility companies to achieve 100% monopoly by eliminating every vestige of competition; and the corresponding reaction to such activity by the cooperative and other consumer owned systems, dissipates the energies of each group and wastes national resources.

A Federally sponsored nationwide system of electric transmission is no less essential to the national economy than is a similar system of transportation highways.

Electric Utilities are not "Free Enterprise"

We know that the program which we herein propose will be castigated as socialistic, unAmerican and contrary to the "traditional American free enterprise system," even though the business of supplying electricity is only remotely related to "free enterprise."

Investor owned utilities are granted monopoly franchises on the theory that they can be regulated by public service commissions, state and Federal, and the courts. Under what other circumstances could a utility be granted a

monopoly to provide an essential public service? How else could they be permitted to operate on a guaranteed cost-plus, profit basis? Their operation is a major outstanding exception to the true concept of "American free enterprise" which implies a freedom of consumer choice; a competitive situation in which the prices and practices of the supplier are to an extent regulated by competition. There is no competition at the retail level in the electricity business. State and Federal regulation substitute for it in theory, but does not consistently perform its task effectively in practice.

The investor owned utilities have grown exceedingly strong because of their monopoly position, because of ineffective regulation, because of their prevailing scarcity and high rate philosophy, because of the $23 billion Federal tax subsidy which they have been granted by way of liberalized depreciation allowances and because the Federal government has failed to provide the "yardstick" of competition by example during the past decade.

They ought now be compelled to produce in the public interest or be sacrificed to it. A vigorous natural resource development program would be a most effective step in the right direction.

A Golden Opportunity

This Committee has a golden opportunity, by the legislative program it recommends, to lead the United States out of the resource deficit position from which it now looks at the future. And by its work thus far, the Committee has assumed the burden of performance in this regard.

The hope of every American for a future of abundance depends on the willingness and ability of this Committee to sustain the burden it has so assumed.

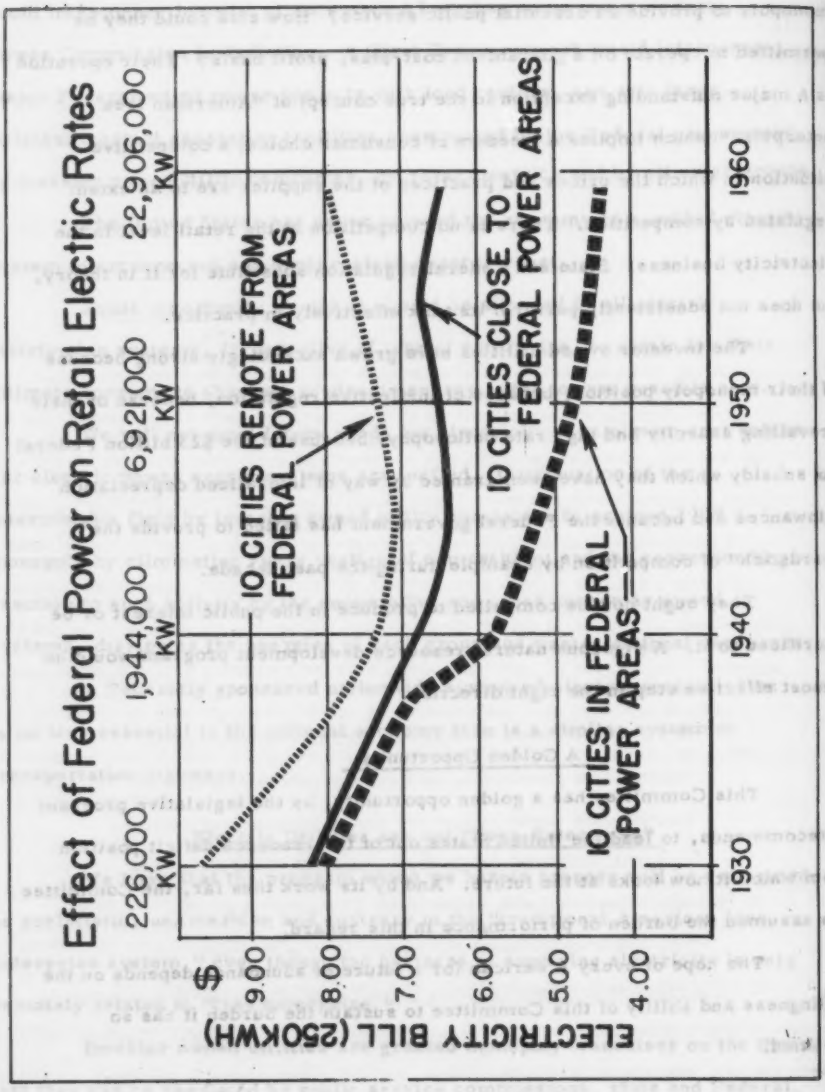

Effect of Federal Power on Retail Electric Rates
226,000 KW
1,944,000 KW
6,921,000 KW
22,906,000 KW
10 CITIES REMOTE FROM FEDERAL POWER AREAS
10 CITIES CLOSE TO FEDERAL POWER AREAS
10 CITIES IN FEDERAL POWER AREAS
ELECTRICITY BILL (250KWH)
$
9.00
8.00
7.00
6.00
5.00
4.00
1930
1940
1950
1960

CHART 1

STATEMENT BY CHARLES E. OAKES

Chairman of the Board, Pennsylvania Power and Light Company on the Subject

PATTERNS FOR TOMORROW'S POWER NEEDS

Submitted in Behalf of the Edison Electric Institute to Supplement the Report Furnished the Committee on January 14, 1960

(Printed in Committee Print No. 10)

The start of a new decade is a good time to pause and take stock as to where we are and where we are going.

The investor-owned utilities have the responsibility to: -

- Furnish an abundant supply of electricity for use in the areas they serve.
- Anticipate future needs well in advance of the time the power will be required.
- Give first-class service at the lowest practicable price to their customers.
- Conduct research and development of all phases of their business in the public interest.
- Assure efficient operation and management by attracting the services of capable and well trained men and women.
- Contribute their full share to the support of our government and the defense of our country.
- Support sound regulation by regulatory bodies at Federal, state and local levels.
- Merit the confidence of: -
  - Their customers,
  - The investors in their securities and
  - The general public
- In every way, be good citizens.

Now, before we go any further let us define what "investor-owned" means as applied to the electric industry. The Edison Electric Institute studies indicate there are about 3.8 million owners of stock of the investor-owned electric companies in the United States--the direct owners of companies

CHART I

just like yours and mine. But there are many more people who have a very great financial interest in our companies.

Approximately one-third of the outstanding debt of America's electric, gas, water, and communication facilities is held by the nation's life insurance companies. Analysis shows that well over half of the 16 billion dollars so invested for the 124 million life insurance policy holders is in electric company securities.

Then there are the more than 22 million depositors in the savings banks of the country, who likewise have a stake in the electric business as substantial amounts of their savings have been placed in power and light securities. Millions of workers whose major support in their old age will come from private pension funds, together with the beneficiaries of trust funds of all kinds, also have a large interest in the investor-owned utilities because these trust funds hold substantial amounts of their securities. Thus almost everyone in the nation has a financial interest in the operation of the electric companies--the investor-owned electric companies.

The investor-owned companies are rightfully proud of the contribution they have made to the nation's economy. They have pioneered in the development of the industry. They have built well. Through technological improvements and good management they have done an outstanding job in holding down the price of electricity despite the wave of inflation that has swept over our country. They have merited the confidence of customers, investors and the general public.

The utilities cannot wait for the market for power to develop, and then proceed to build to meet it. They must plan far ahead so that the public can be assured of always having available an abundant supply of electric power. The investor-owned companies have been highly successful in doing this

for the record shows that no power shortages of consequence have occurred in the areas they serve, even under the stress of war. For a number of years the industry has studied its capacity situation and provided the public with factual information through its Electric Power Survey reports.

To date we have met our responsibilities in full. We confidently expect to do so in the years ahead. Each company is well informed as to where it is, and where it is going. Every utility keeps up-to-date forecasts of the power needs of its area, and has formulated plans to meet its future power requirements.

To assemble this information and thinking on an industry basis, the Edison Electric Institute has been reviewing past history, surveying forecasts made by economists of national standing, and preparing estimates of its own as to what is ahead for the entire industry and for the investor-owned electric utility companies in particular. Definite figures have been prepared for 1970 and 1980, with some general estimates even as far ahead as the year 2000 for certain phases of the study.

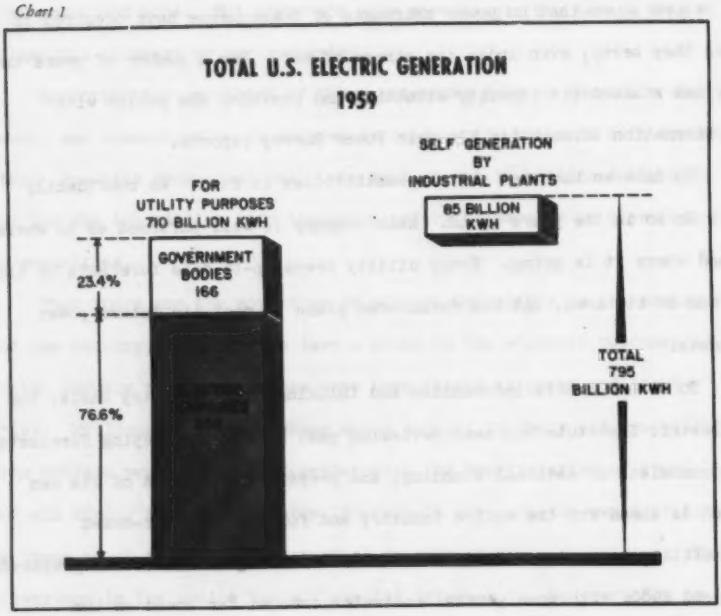
Let us look at some of these forecasts as a guide to what is ahead for the electric industry, and the public it serves. But first let us establish the solid basis on which these forecasts rest.

CHART 1

In the year 1959, a total of 795 billion kilowatt-hours of electricity was generated in the United States. This total is the one furnished to the United Nations for use in international comparisons.

Of this great amount, 85 billion kilowatt-hours, or a little more than one-tenth, were produced by industries for their own use. The remaining 710 billion kilowatt-hours were produced by utilities for resale to ultimate consumers.

Chart 1



The utility industry is in two parts--the investor-owned utilities on the one hand, and government bodies in the power business along with rural electric cooperatives on the other. Of the utility total, the investor-owned companies generated 544 billion kilowatt-hours, and the government bodies and electric cooperatives produced the remaining 166 billion.

The two sections of the utility industry are interrelated, in that power and energy is bought and sold between them. Slightly different percentages prevail with other measures of size; a convenient overall figure is about three-quarters for investor-owned companies, and about one-quarter for government bodies and co-ops.

CHART 2

The use of electric power on a national basis is influenced by the development and requirements of business and industry, by the growth in population and the rise in the level of living standards. These are the underlying causes which affect the need for electricity--causes which are closely related to the expansion of the nation's economy.

This chart shows the record of population growth since the turn of the century. The Census Bureau has recently prepared new forecasts of the probable population of this country. The Census figures are based on maximum and minimum fertility. The Edison Electric Institute has taken figures in between--namely, 208 million people in 1970 and 245 million in 1980. The year 2000 is not shown on the chart, but the Institute advances 340 million people as a likely figure for that year.

Chart 2

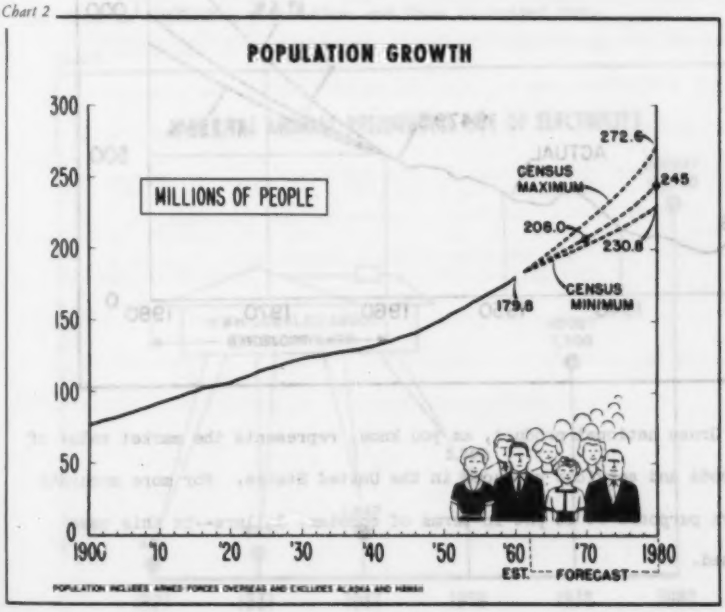
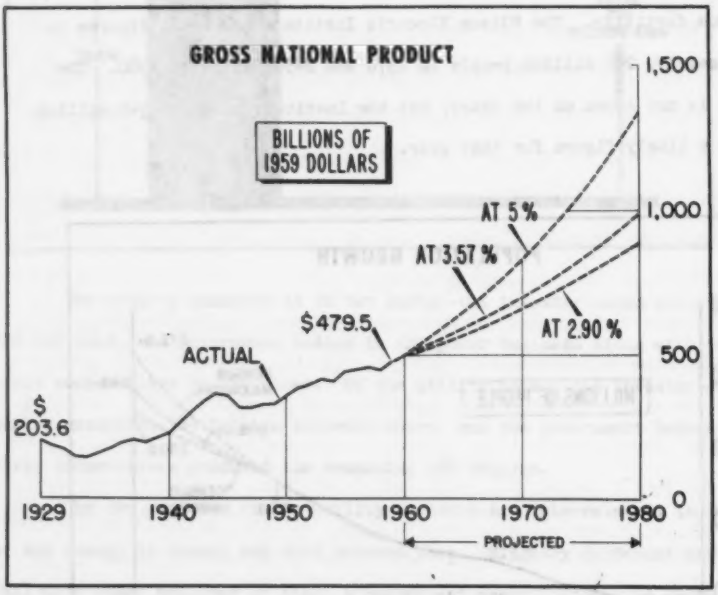


CHART 3

This chart shows gross national product from 1929 to 1959. The bottom projection to 1970 and 1980 is at 2.9 percent, which is the average rate of increase from 1929 to 1959. Some people talk about a rate of growth as high as 5 percent. The 3.57 percent increase, which is the one used in the Edison Electric Institute study, represents what is probably a more realistic appraisal as it is the average rate of increase for 1946 through 1958--the postwar period.

Chart 3



Gross national product, as you know, represents the market value of all the goods and services produced in the United States. For more accurate comparative purposes it is put in terms of constant dollars--in this case 1959 is used.

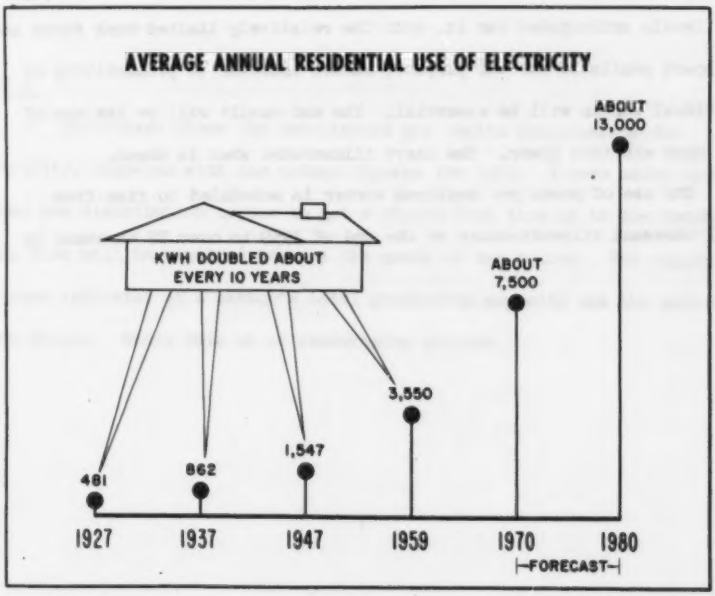
An analysis of the historical trends in kilowatt-hour sales, shows the existence of close relationships between sales in the various customer classifications and certain components of gross national product.

For example, residential sales are related to disposable income--that is, the income people have left after tax payments to government. Commercial kilowatt-hours tie in with personal consumption expenditures as represented by the market value of goods and services purchased by individuals. Industrial electric sales follow closely the industrial activity throughout the country which is measured by the Federal Reserve Board index of industrial production. Thus, we believe these forecasts for the industry rest on a solid foundation.

CHART 4

The task of extending electric lines to the American public is virtually complete. Future gains in power sold to home and farm will largely come from an expanding population and from increased use.

Chart 4



The average residential use of electricity for the United States is shown in this chart. Some utilities have already passed the nation-wide average-use forecast for 1970. And many individual homes are now using more than the national average forecast for 1980--13 thousand kilowatt-hours.

An average size, all-electric home will use over 20 thousand kilowatt-hours a year. So even in 1980 there will still be a big market for the sale of electric power in the households of our country.

The household of tomorrow will be highly mechanized through electric power. Climate control will be commonplace with electric heating in winter and air-conditioning in summer. Even the family car may be driven by electricity. And there will be many other beneficial uses we cannot foresee today.

CHART 5

Increased productivity in shop and office has as one of its main components the use of electricity. If our nation is going to reach the economic levels anticipated for it, with the relatively limited work force and working hours available for the purpose, marked increase in productivity of the individual worker will be essential. The end result will be the use of more and more electric power. The chart illustrates what is ahead.

The use of power per employed worker is scheduled to rise from around 12 thousand kilowatt-hours at the end of 1959 to over 22 thousand by 1980.

Chart 5

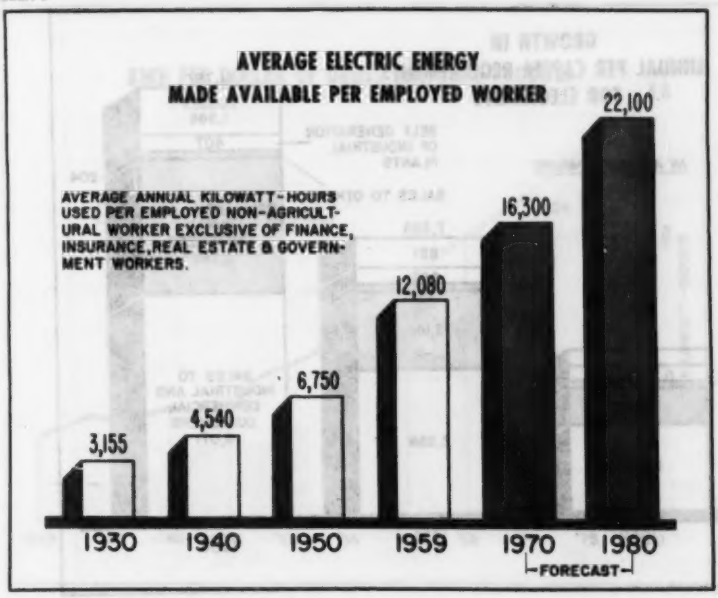


CHART 6

This chart shows the anticipated per capita requirements for electricity, compared with the actual figures for 1959. I have added transmission and distribution losses to get a figure that ties in to the amount of energy that will be required to meet the needs of our nation. Per capita use is a good indicator of a nation's total productive capacity and the well-being of its people. Hence this is an encouraging picture.

Chart 6

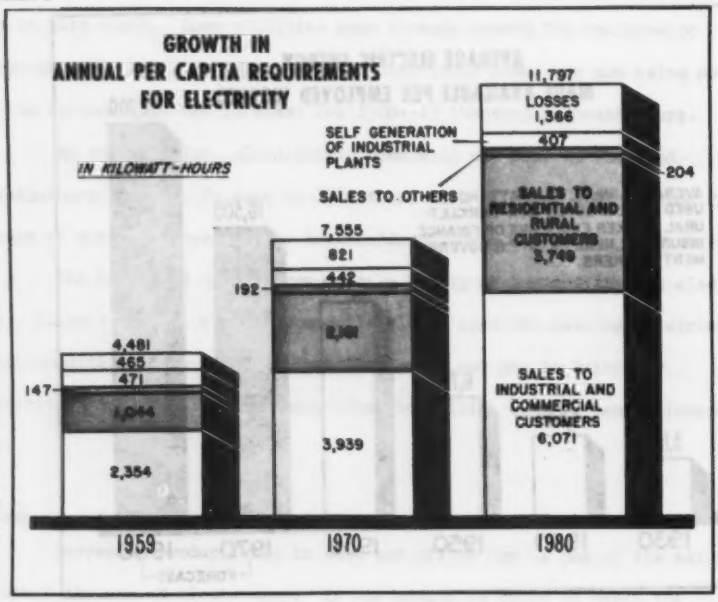


CHART 7

The economists foresee for 1980 a value of our nation's goods and services of nearly one trillion dollars in terms of constant dollars--double today's figure. To reach this level will require a greatly expanded use of electricity--almost 3 kilowatt-hours per dollar of gross national product in 1980 as compared to only 1-2/3 kilowatt-hours today.

Chart 7

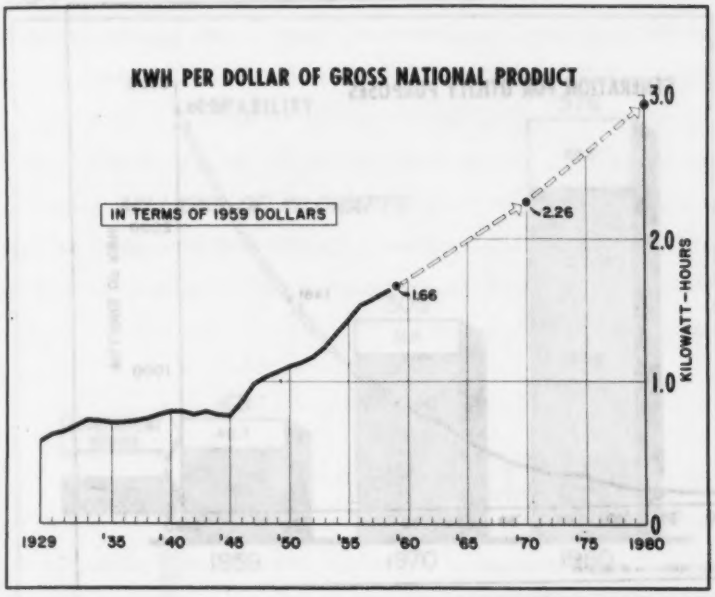


CHART 8

This summary chart shows the total amount generated for utility purposes from 1930 through 1959 compared with the power generation forecast for 1970 and 1980.

Let us visualize what this growth means. The electric industry will generate as much energy in the next ten years as it has produced during its entire history to date. And, in the decade of the seventies, the estimates show a production of over three times the energy that it has turned out from the day of Edison's invention of the incandescent lamp to the end of 1959.

Chart 8

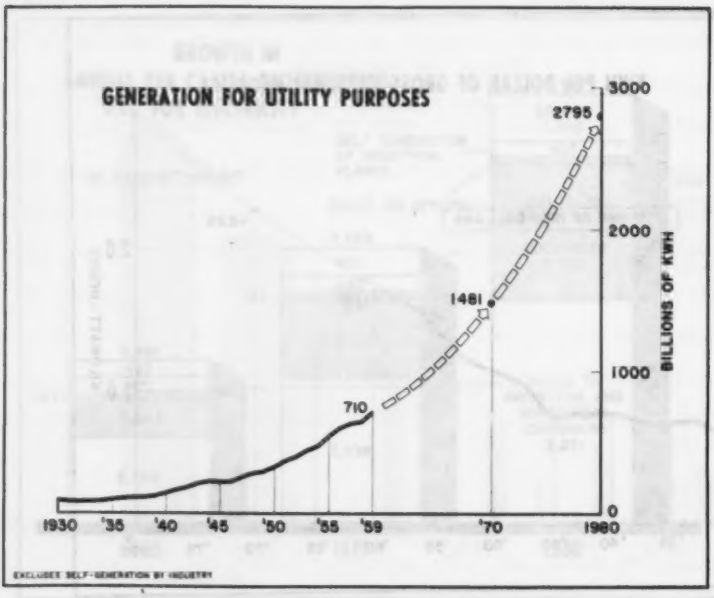


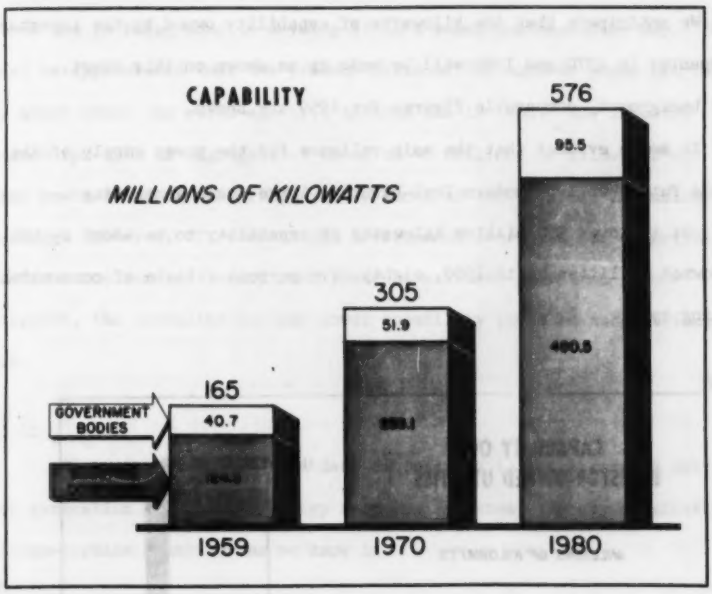
CHART 9

One of the most important things our industry's study group did was to determine how much power plant capability was needed to produce this vast amount of energy and how it would be made up.

This chart shows the anticipated capability necessary to produce the amount of energy required to supply the needs of our people in 1970 and 1980. For comparison purposes, we have shown the situation as it existed at the end of 1959.

The chart shows the breakdown of capability between the investor-owned companies and the government bodies and cooperatives.

Chart 9



By 1980, 411 millions of kilowatts of new capability must be built, of which 87 percent is the job of the investor-owned utilities.

The figures shown for the investor-owned utilities represent the long-range plans of the companies to meet the needs of the areas they serve. You will note that the forecasts show a substantial amount of capability to be installed by government and cooperatives.

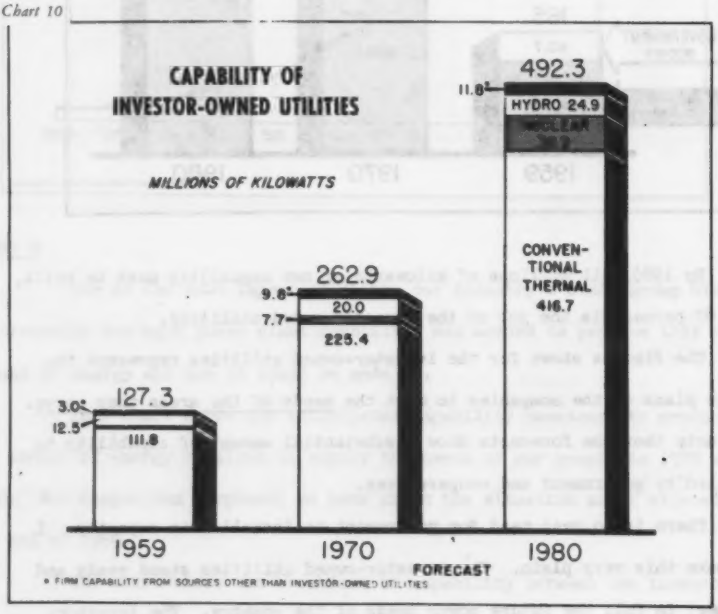
There is no real need for government to install this capacity. I want to make this very plain. The investor-owned utilities stand ready and able to meet in full the future power needs of the country. The investor-owned companies are ready to enlarge their plans to supply all the necessary facilities, including the part of the program indicated for public power on the chart, and will do so if given the opportunity. This would result in enormous savings in tax dollars which will otherwise be spent needlessly.

CHART 10

We anticipate that the kilowatts of capability owned by the investor-owned companies in 1970 and 1980 will be made up as shown on this chart. Again for background, comparable figures for 1959 are shown.

It seems evident that the main reliance for the power supply of the foreseeable future will be modern fuel-burning, large-scale generating stations. Of the over 356 million kilowatts of capability to be added by the investor-owned utilities up to 1980, eighty-five percent will be of conventional fuel-burning type.

Chart 10

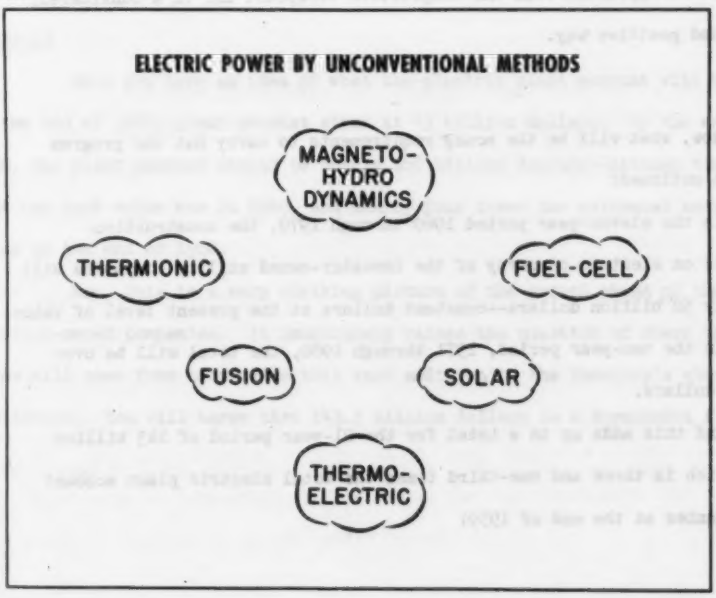


Nuclear power is on everybody's mind. A monumental amount of work has been and is being done to develop it in a sound business-like way. But it must be appreciated that the present state of the nuclear power art is today about where the steam-electric turbine was in 1920. The industry estimates for 1980 an aggregate of close to 40 millions of kilowatts of nuclear power based on what is presently known of the progress in nuclear technology. However, if research and development overcomes the competitive gap between nuclear and fossil fuel power at a faster pace than is now anticipated, the installed nuclear power capability could be substantially larger.

CHART 11

In another area, a great deal of research is being carried out in the direct generation of electric energy from fuel sources, thereby eliminating the steam-turbine generator as we know it.

Chart 11



As the years go by you will hear more about direct generating sources, such as --

Solar	Thermionic
Thermo-electric	Fuel-cell
Magneto-hydrodynamics	Fusion

It hardly seems possible that any of these methods can get out of the laboratory in the next ten years insofar as central station power is concerned. But while only a few short years ago we foresaw nuclear energy as the only fuel on the horizon to offer competition to fossil fuels, we now envision that nuclear fuel itself may have real competition fifteen or twenty years hence. And furthermore, we are now assured that there will be ample fuel sources to power American industry and civil life for hundreds of years to come.

These advances in research of new methods of power generation emphasize that the development of nuclear power as well as these still newer sources must be appraised from the competitive viewpoint and in a considered, judicious and positive way.

CHART 12

Now, what will be the money requirements to carry out the program I have just outlined?

In the eleven-year period 1960 through 1970, the construction expenditures on electric property of the investor-owned utility companies will total nearly 52 billion dollars--constant dollars at the present level of value.

In the ten-year period, 1971 through 1980, the total will be over 91 billion dollars.

And this adds up to a total for the 21-year period of 143 billion dollars, which is three and one-third times the total electric plant account of the companies at the end of 1959!

Chart 12

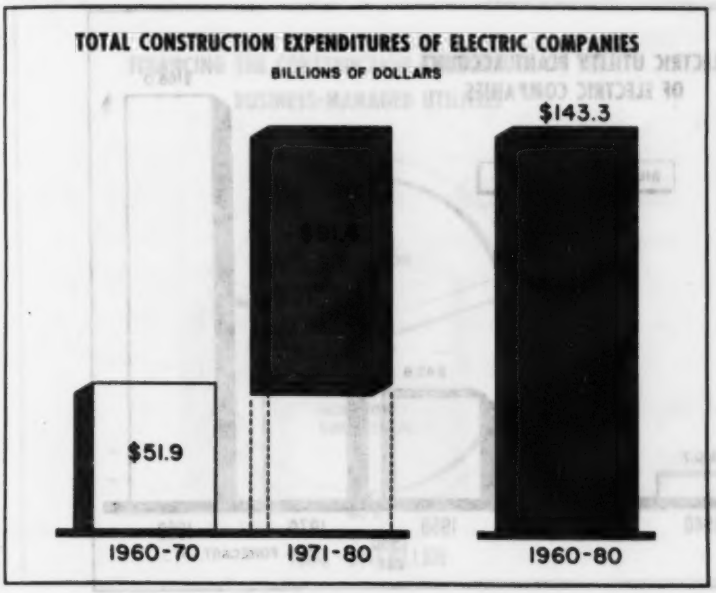


CHART 13

Here you have an idea of what the electric plant account will be. At the end of 1959, plant account stood at 43 billion dollars. By the end of 1980, the plant account should be nearly 168 billion dollars--sixteen times what the book value was in 1940, and nearly four times the estimated book value at the end of 1960.

Now, this is a very striking picture of the growth ahead of the investor-owned companies. It immediately raises the question of where the funds will come from to provide this vast addition to the industry's electric facilities. You will agree that 143.3 billion dollars is a formidable figure.

Chart 13

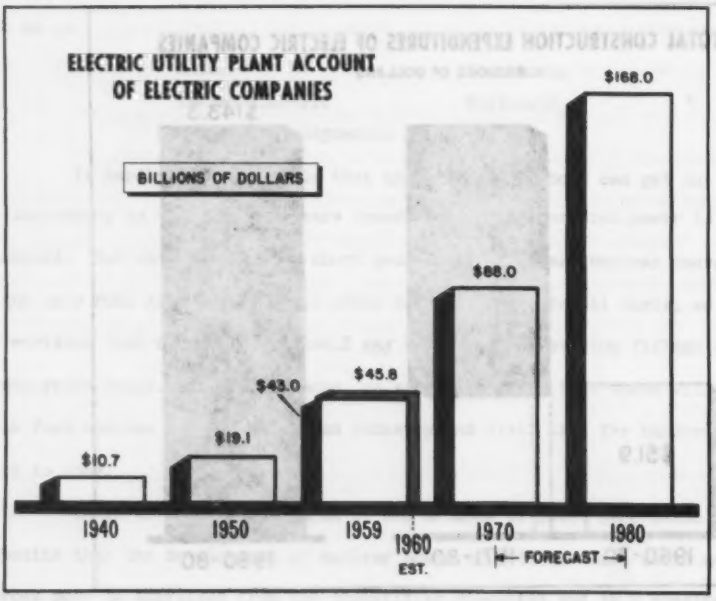


CHART 14

With a continued sound economy, fair regulatory treatment of the utilities of the country and assuming a constant value of the dollar, the electric companies should be able to generate in the day-to-day operation of the business about 58 billion dollars--around 40 percent of the total needed. The rest will be new money--85 billion dollars--which will have to come from the sale of securities to the investing public. A staggering sum to be sure. But there seems to be no reason why this cannot be done with success and with proper maintenance of sound capitalization ratios and fair dividend treatment of the equity investor. Should inflation continue, however, a much larger amount of new money would be needed, as a smaller proportion would be generated by the business.

Chart 14

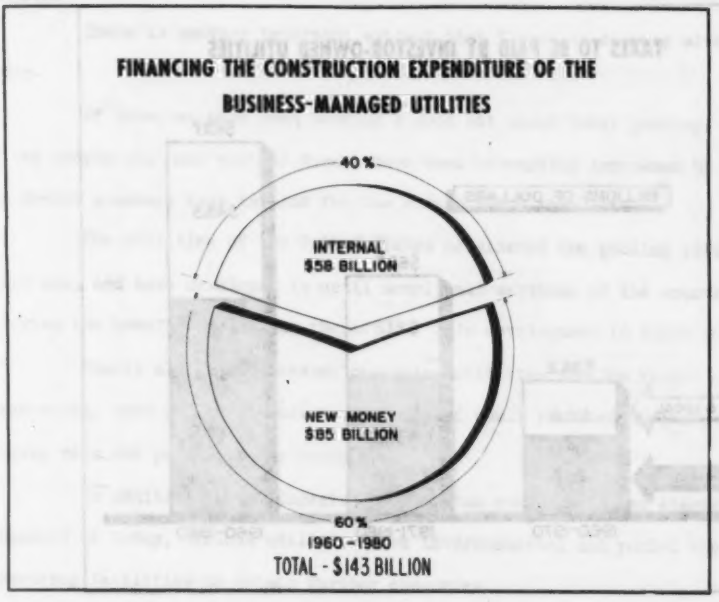


CHART 15

The study indicates that the investor-owned utilities are prepared to meet fully their responsibilities to the people of our country.

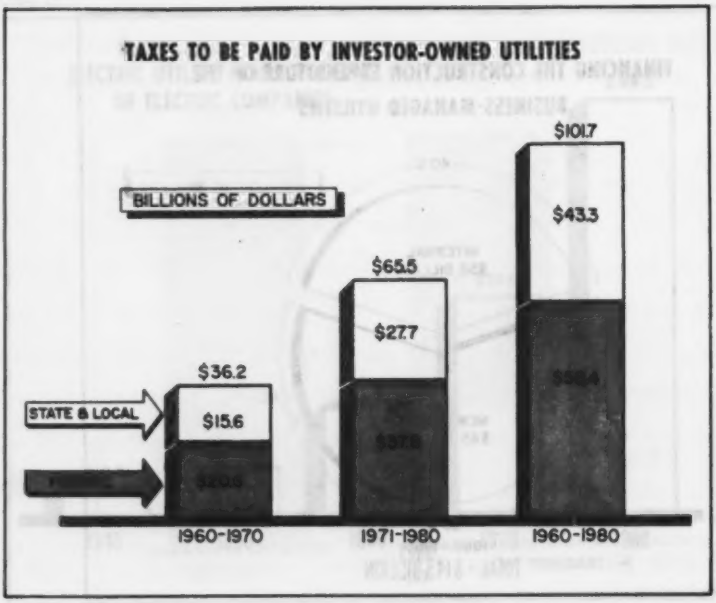
They are prepared to raise their own capital in the free money market, without recourse to the public treasury.

They have adequate plans to assure ample electric power in future years.

They will continue their pioneering so that the people of this country will receive in full measure the benefits of research and new discoveries in the utility field.

And unless inflation gets out of hand, they will be able to continue to hold the price line which, on the whole, they have been more than successful in doing as compared to general price levels.

Chart 15



You may find significant this illustration which shows the vast size of the tax bill, based on present tax rates, during the years to come--a total of nearly 102 billion dollars in the twenty-one year period shown!

Of course these taxes are included as an element in the cost to serve the customer. We, and I think our customers, are willing to pay our fair share of taxes but we think all business, including government business enterprises, as a matter of equity should also bear their share. But thus far, government business undertakings have failed to do so.

CHART 16

There is another important subject that I want to discuss with you today.

Of late, we have been hearing a good bit about power pooling. Some of the people who have visited Russia have been ostensibly impressed by what the Soviet planners have in mind for the future along this line.

The utilities of the United States originated the pooling idea many years ago, and have developed it until nearly all sections of the country are enjoying the benefits resulting therefrom. This development is still going on.

Nearly all of the present operating utilities are the result of integrating, over a 60-year period, hundreds of small isolated systems, merging them and pooling their resources.

In addition to the integration that has resulted in the electric companies of today, various utilities have interconnected and pooled their generating facilities to obtain further economies.

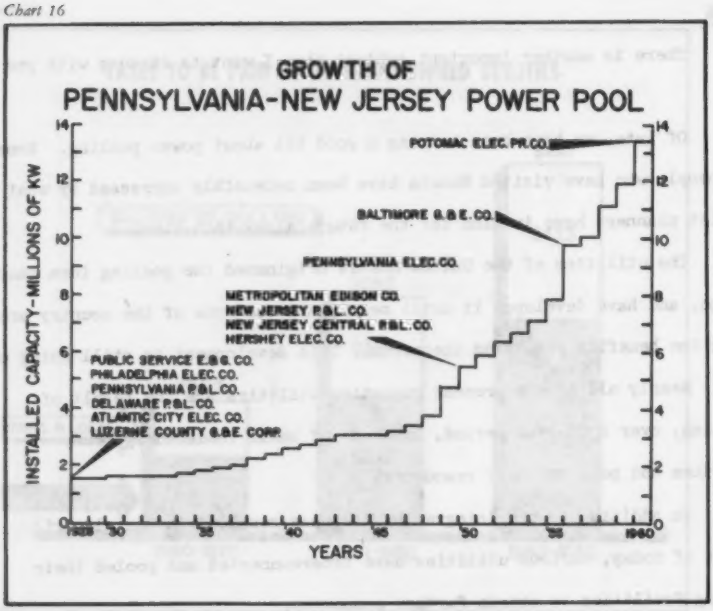
May I refer to my own company's experience--Pennsylvania Power & Light Company--as a good example of what has taken place many times over the years in this field.

Step by step over 900 separate parts were consolidated to form the Pennsylvania Power & Light Company as it now exists.

I want to illustrate the next step by this chart.

More than 36 years ago, in 1924, representatives of Public Service Electric & Gas, Philadelphia Electric and Pennsylvania Power & Light met to investigate the feasibility and desirability of a high voltage transmission interconnection among the companies. As a result of this pioneering, a 220 thousand volt backbone loop was built. At the time, this was the highest voltage in use in this country.

Chart 16



Then step by step as illustrated on the chart, the present regional power pool, consisting of 13 companies with a total generating capability of 13.5 million kilowatts, was developed. The strengthening and expanding process is going on today. As recently as May 1st of this year, Potomac Electric Power Company joined the pool. I can assure you that we do not intend to stop where we now are. We plan to continue to improve our pooling facilities and operations which have proved to be very beneficial to the customers of all the participants.

Parenthetically, I would like to give you some interesting figures about the companies in this power pool. Their aggregate capability at the end of 1959 was 12 million kilowatts. Tennessee Valley Authority's capability as of the same date was 11.7 million kilowatts.

In the year 1958, the twelve participants then in our power pool set aside a total of over 183 million dollars for taxes.

Of this tremendous sum nearly 113 million dollars represented Federal income taxes, and about 70 million dollars represented other taxes.

T.V.A. and its resale distributors paid no Federal income taxes. T.V.A. made a payment of nearly six million dollars in lieu of state and local taxes and its resale distributors made a similar payment of slightly over nine million dollars.

In other words, the taxes of the twelve power pool participants amounted to over twelve times the total payments made by T.V.A. and its resale distributors in lieu of taxes.

Today there are many other similar power pools throughout this country. They range from formal organizations to informal exchanges of economy power, power purchase agreements or simple emergency service connections. Their histories resemble the one I have just outlined to you. They, too, continue to expand. For example, the major investor-owned utilities in New York State have just announced a plan to build a major tie between upstate New York and the metropolitan area.

Utah Power & Light Company and Arizona Public Service are preparing to interconnect their electric systems to take advantage of load diversity.

There are many other examples that I could cite.

All of these ties have one main objective, which is to furnish good service to the public at the lowest possible rates. They are so much a part of our daily operations in this country that we take them for granted.

CHART 17

Sometimes it is instructive to look at the record. Let us see what it shows. Here is the transmission system in the United States in 1908, which was fifty-two years ago. You can see that a start on interconnections had already been made.

Chart 17

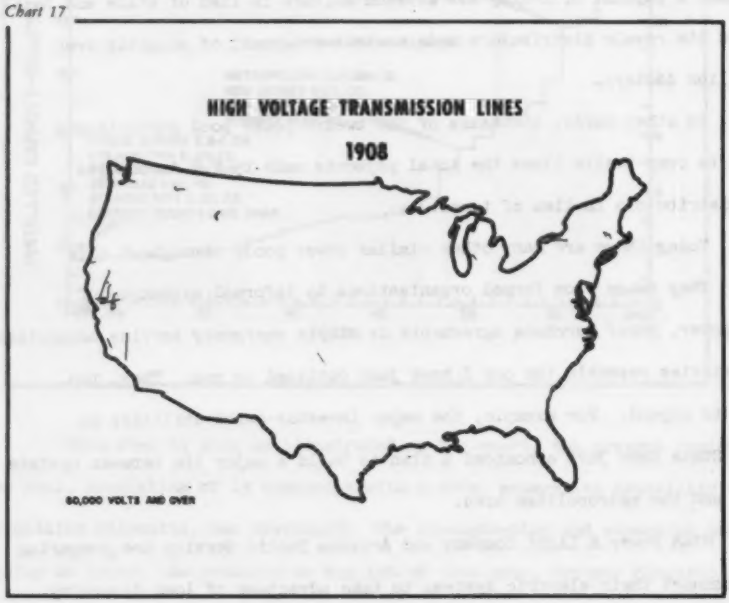


CHART 18

This map shows the situation in 1918--only ten years later. The reason for the early high-tension lines in the Pacific Coast area was that many of the early generating stations in that section were hydro, and the lines were required to tie them together and get power to the load centers.

Chart 18

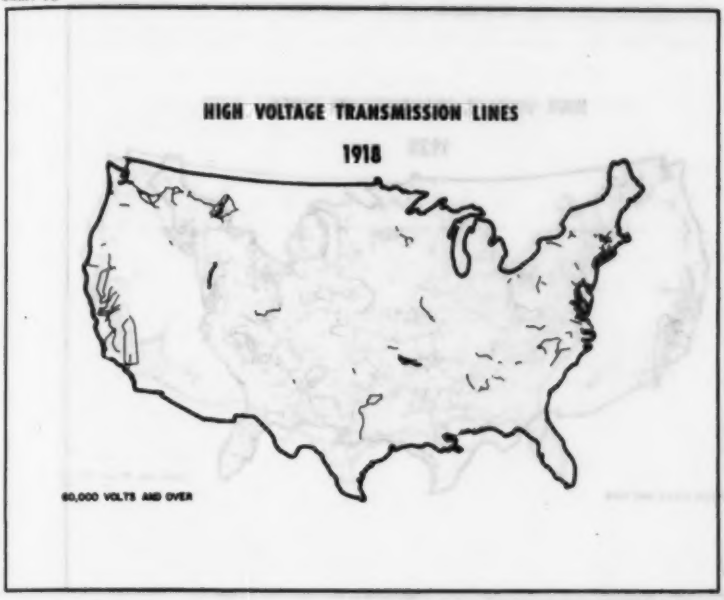


CHART 19

Pooling really advanced in the next ten years, as is shown by the 1928 map. You can see the beginning of the Pennsylvania-New Jersey power pool, which I mentioned a few moments ago. Backbone transmission was being built throughout the nation, especially in the east and on the west coast.

Chart 19

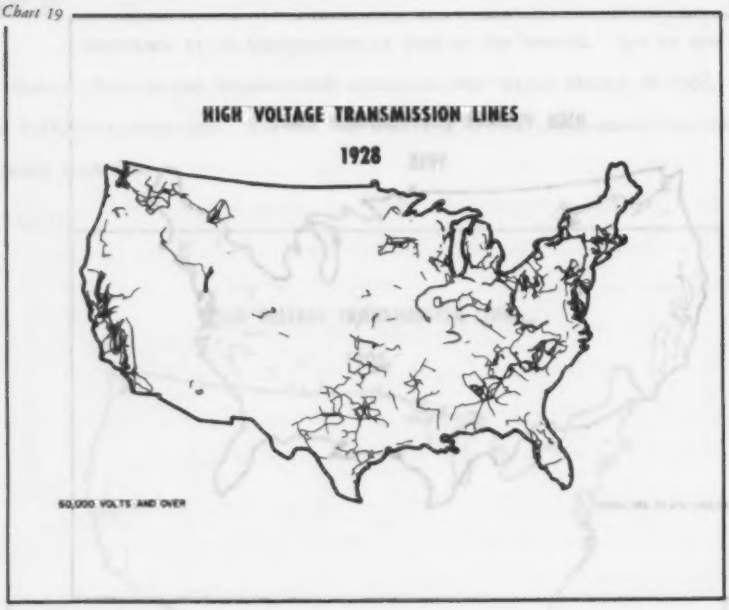


CHART 20

The next map shows the high lines in existence in 1940. Area interconnections were far advanced by that prewar year. One of the main reasons for the ability of the utilities to meet the full power needs of the country throughout the war period, was the existence of this great grid.

Chart 20

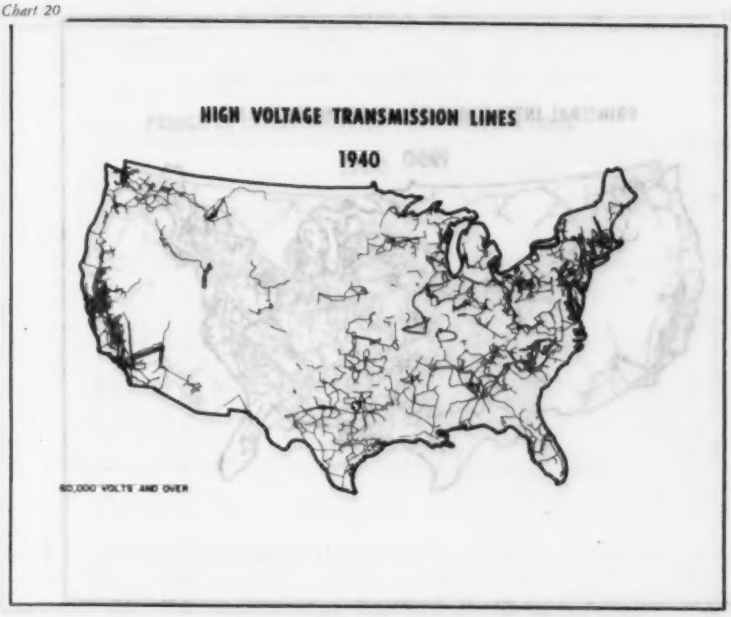


CHART 21

Another big step forward appears on this 1950 map, which shows, for the first time in this series of illustrations, some lines under 60,000 volts that were important parts of the national network.

Chart 21

CHART 22

This last map shows the situation today. It also is different from the earlier maps in that some of the lower voltage transmission lines are shown in addition to the backbone transmission. It illustrates the wide coverage of the transmission system of this country--a huge network of power lines.

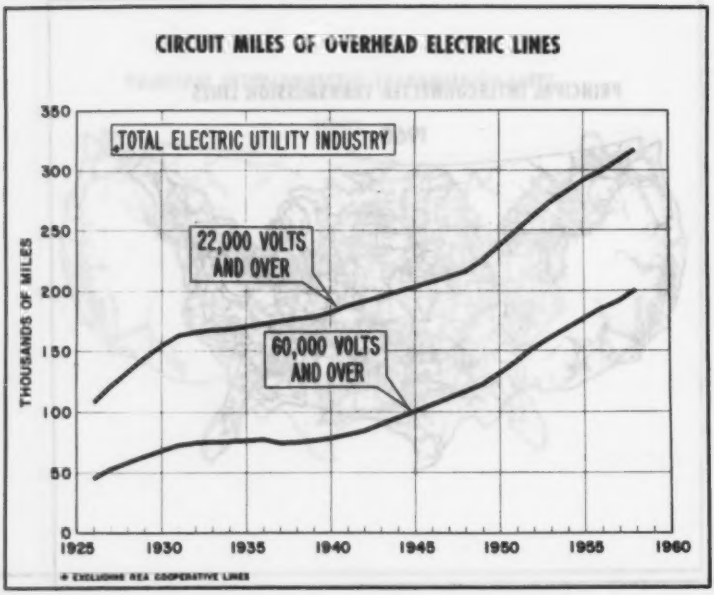
Chart 22

CHART 23

This chart shows the mileage of the transmission lines of the United States of 22,000 volts and over, together with the lines of 60,000 volts and over. You will note the great expansion that has taken place since 1950.

As the generating capacity grows to take care of the expanding load, the interconnection and pooling process is accelerating all over the United States.

Chart 23



Although conditions are constantly changing, the basic benefits of interconnection and pooling remain much the same. Not all these benefits are possible in every situation. I have listed nine major benefits; there are other special benefits that can be realized in individual instances. Here is my list:

. Savings in production expenses, where differentials exist in fuel cost, efficiency and operating expenses other than fuel. The general practice is to place the low-cost stations on base load, and to schedule the others in the order of their efficiency.

. Lower transmission losses. Line voltages to be selected have a direct relation to the amount of power involved, the distances to load centers, and the value of the losses.

- Reduction in the amount of reserve generating capacity. This advantage is especially important today because of the large-sized units being installed.
- Taking advantage of load diversity, including differences in time zones. The growth in summer peak demands emphasizes the importance of this factor.
- Greater leeway in planned maintenance. The ability to draw on spare capacity in the pool gives greater flexibility in the increasingly difficult task of scheduling maintenance.
- Ability to install larger and more efficient generating units. This is of special advantage to smaller utilities that cannot by themselves justify installing generating units of optimum size.
- Improved emergency service. A pool gives added insurance to the maintenance of service during catastrophies and accidents to major equipment.
- Contribution to national defense. In the event of bombing or sabotage, a pool will greatly aid in maintaining service. It will also give greater flexibility to locating defense projects.
- Making possible full use of the various low-load factor hydros now in existence and to be built in the future. Pumped storage projects, where conditions are favorable, offer advantages to the pooled systems of the future.

As I look at the future of the investor-owned utilities, these are some of the opportunities that we have before us.

As the loads grow and the capacity increases, further expansion of power pooling offers possibilities of additional savings and improved operation.

This growth will be on a regional basis, and will be governed as to extent and type by local conditions. The process will be aided by long range planning of transmission lines and interconnections. The most successful power pools of today exist in situations where this has been done in the past.

Savings in capital expenditures can be obtained through standardization of turbines and generators over the entire range of sizes used by the industry. The possibilities seem to be especially favorable in respect to large-sized units operating under high pressures and temperatures. The standardization process should be related not only to sizes, but also to pressures and temperatures.

The idea could well be extended to other items of equipment.

To carry out this idea, the industry should not expect the manufacturers alone to do the job. The companies must take the lead in this matter, but they must take great care that standardization does not develop into a "road block" to future technological progress.

As the demand grows for additional power, great use will be made of the maximum size of units suitable for each situation. Greater opportunities will present themselves to locate on advantageous sites, in respect to load centers, fuel, water and the many other factors involved in power plant location.

Manufacturers tell us that they are willing and able to make a unit of a million kilowatts, and that there is no technical barrier to line voltages of one million volts or even higher.

It is my belief that it would be advantageous to both the manufacturers and the utilities, if the two got together, and scheduled the new units to be installed in such a manner that the manufacturing facilities would have a uniform rate of production.

As we push ahead into the last half of this century we can look for a rapidly increasing economic momentum. Population will continue to grow.

Business and industry promise substantial expansion. Research and scientific development offer assurance of even greater progress in the coming years than we have seen in the past.

But to realize fully what the future holds depends in great measure on what we do today. Wise long-range planning in the use of our resources is needed. It is toward this end that our industry is taking this look ahead. What we have projected is a realistic appraisal. The investor-owned utilities are well prepared to take care of the greatly augmented power needs of the future, standing on their own feet, and to do so without recourse to the public treasury.

I am confident that we merit the public's support necessary to carry out the program that I have outlined to you today.

But we must tell our story. Our own customers do not know these facts and we must accept the responsibility to see to it that they are informed.

A recent opinion survey for the Electric Companies Public Information Program, based on a properly selected sample of electric company customers, shows that only 52% of our customers believe that our companies can be relied upon to provide all the power that is needed for our country's future. Some 29% believe that government help is required. And 19% do not know if they can rely on our companies or whether government help is necessary.

Here is the key fact: More than two-thirds of the 29% who said that government help is needed took this position because they feel the job to be done is "too big" or "too expensive" for our companies to handle. Here again we have proof that the lack of widespread knowledge of the facts about our industry's past record, our plans, our capabilities and our resources, is what is really hurting us. And it is hurting us much more than any ideological bias against our industry, yet is much easier to correct.

So let us tell the story of our industry's capability to meet tomorrow's power needs. And let us continue to bear in mind that though this story may come to be old and familiar to us, this is not the test. The criterion is widespread knowledge and information about the electric industry. We must keep at our information work and programs until the evidence at hand much more fully demonstrates that in this area we have done the job that is before us to do.

The CHAIRMAN. The committee will recess subject to the call of the chairman.

(Whereupon, at 3:15 p.m., Thursday, May 26, 1960, the committee recessed subject to call.)

(The following letters and statements were received subsequent to the closing of the hearing:)

HON. JOHN L. MCCLELLAN, U.S.S.
CHAIRMAN EMERITUS
HON. OVERTON BROOKS, M.C.
CHAIRMAN
HENRY H. BUCKMAN
PRESIDENT
WILLIAM H. WEBB
EXECUTIVE VICE PRESIDENT
WILLIAM V. BAILEY
SECRETARY
WM. G. REYKMANN
TREASURER

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NATIONAL RIVERS AND HARBORS CONGRESS

1028 CONNECTICUT AVE., WASHINGTON 6, D. C.

NATIONAL VICE PRESIDENTS
HON. JOSEPH W. MARTIN, JR., M.C.
HON. ALEXANDER WILEY, U.S.S.
HON. SPESSARD L. HOLLAND, U.S.S.
HON. JOHN A. BLATNIK, M.C.
HON. ROBERT L. F. SIKES, M.C.
HON. RALPH W. YARBOROUGH, U.S.S.

6 June 1960

Honorable Robert S. Kerr, Chairman
Select Committee on National Water Resources
United States Senate
Washington 25, D. C.

Dear Mr. Chairman:

There are enclosed reports of the following Committees which were adopted by the delegates in attendance at the 47th National Convention of the National Rivers and Harbors Congress held 24-27 May 1960 in Washington, D. C.:

Projects Committee - Rep. Phil Weaver of Nebraska, Chairman
Resolutions Committee - Rep. Paul G. Rogers of Florida, Chairman
Irrigation and Reclamation Committee - Rep. J. Edgar Chenoweth of Colorado, Chairman
Industrial and Municipal Water Use and Pollution Abatement - Rep. John A. Blatnik of Minnesota, Chairman
Wildlife and Recreation - Rep. Ed Edmondson of Oklahoma, Chairman

This convention was attended by 371 registered delegates and their ladies from 49 states, Puerto Rico, the Virgin Islands and the District of Columbia, in addition to several score un-registered delegates, guests, visitors, representatives of the press, radio, television, etc.

These delegates were from all sections of the country, representing both legislative and executive branches of the Federal Government; state, city, county and other local governmental agencies and interested groups; commercial, waterway, flood control and reclamation associations; agricultural, labor, industrial and trade organizations, and transportation interests; with memberships totaling several million.

We believe this expression of representatives of such different interests and pursuits is strong evidence of the general sentiment of the people of the United States concerning the matters dealt with in these reports, and we shall greatly appreciate your careful consideration of these recommendations.

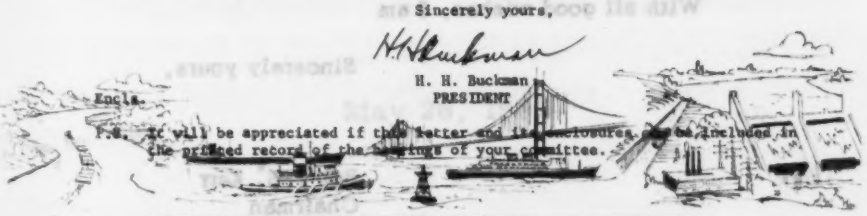
Sincerely yours,

H. H. Buckman

H. H. Buckman
PRESIDENT

Encls.

P.S. It will be appreciated if this letter and its enclosures can be included in the printed record of the hearings of your committee.



DEDICATED TO THE SCIENCE OF WATER USE, CONTROL AND CONSERVATION

COPY

June 10, 1960

H. H. Buckman, President
National Rivers and Harbors Congress
1028 Connecticut Avenue, N. W.
Washington 6, D. C.

Dear Mr. Buckman:

Thank you for your letters of June 6, enclosing Committee reports to the 47th National Convention of the National Rivers and Harbors Congress, and requesting that they be included in the record of the hearings of the Senate Select Committee on National Water Resources.

We are very glad to have this expression of views of the groups represented by your organization and we will be very glad to include the Committee reports in the record of our May 26 hearing.

With all good wishes, I am

Sincerely yours,

Rob't S. Kerr
Chairman

Report of the

Resolutions Committee

to the

47th National Convention

of the

NATIONAL RIVERS AND HARBORS CONGRESS

May 26, 1960

FOREWORD

The National Rivers and Harbors Congress assembled in its forty-seventh annual convention hereby rededicates its entire effort to the continued development of our great Nation through the development of our two major resources - our land and water. We intend to do our utmost now while it is appropriate and thereby help to strengthen our Nation to enable it to better meet adverse conditions should they ever return. In fact the strength so gained will go far toward avoiding such adverse conditions.

POLLUTION OF INLAND WATERS

This Congress for some time has recognized the problem of pollution of our inland interstate waterways and impoundments by boats, municipalities and industries. Millions are spent to improve the waters only to have them used by improperly equipped marine craft which cause pollution by disposal of sewage and other wastes and also such waters are polluted by improper disposal of industrial waste by industries and sewage by municipalities. We urge the Surgeon General of the United States Public Health Service and his interagency study group concerned with this major problem to make an early and appropriate report to the National Congress to form a basis for remedial legislation.

DOCK AND MOORAGE STANDARDS AS AIDS TO NAVIGATION

For some time now restrictions to navigation occasioned by structures along our navigable channels have been on the increase. Larger and faster vessels will make the problem more serious in the years ahead if some equitable solution is not found. While it would appear that Federal regulation might provide protection to operating vessels and shoreside facilities, it may well be that local zoning ordnances may provide standards of construction and location to insure that such facilities withstand normal vessel passages without damage. This Congress will dedicate its efforts to a resolution of this serious problem.

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FLOOD PLAIN ZONING

This Congress recognizes the need for some form of regulation to avoid the creation of flood hazards in the future in the flood plains of the rivers of our country. In this connection we strongly support the view of the Chief of Engineers as expressed in his opening statement concerning the Fiscal Year 1961 appropriation for civil functions. The action proposed by him is appropriate and this Congress will support legislation which would authorize the Corps of Engineers to provide flood plain information and advice to communities, to aid them in their planning for regulation of flood plain use. We share his belief that such information will serve as a guide to local development and as a means of avoiding future flood hazards.

LOSS OF RESERVOIR SITES

Consistent with long range planning for the orderly development of our water resources we subscribe to the principle that definite action is indicated to preserve reservoir sites for that purpose. Major housing developments, industrial expansion and the highway system have already exacted their toll on the remaining reservoir sites. Natural reservoir sites are a natural resource that should be preserved. Advance acquisition of appropriate estates in land or options therefor will be objected to. However, we urge the Committees of Congress to continue to pursue the problem before these necessary sites are pre-empted for other uses.

THE NEW MAINTENANCE PLAN OF THE CORPS OF ENGINEERS

We are impressed with the plan for improving the maintenance program of the Corps of Engineers which has been devised by the Corps of Engineers in cooperation with the Bureau of the Budget. This plan, presented to the Congressional Appropriations Committees by the Chief of Engineers in his opening statement in 1960 is an indication that an effort has been and is being made to reduce the backlog of maintenance on flood control and navigation improvements in which the Nation has a large investment. We strongly urge the Congress to implement the program by adequate appropriations. This plan of funding rehabilitation of major rehabilitation projects separately and small projects in a lump sum should give the Committees a much better understanding of the problem and the urgent need for such appropriations.

TOLLS ON WATERWAYS

We are convinced that our continuing opposition to user charges on tolls on waterways is correct. There can be no doubt that such charges will result in a higher cost for water transportation and will produce a shift of such transportation from water to land. The investment already made for waterways warrants their continued full use. User charges will decrease that use and consequently they will provide a lesser return upon this extensive development.

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RECREATION

Recreation at completed projects of the Corps of Engineers and the Bureau of Reclamation has become an important asset of these major investments. However, the Congress has not yet defined the extent of the Federal interest in such assets as a function of water resource development. We feel that it is now appropriate for the Congress to do so. In so doing it should establish guide lines for evaluating these benefits and allocating their costs.

OBSTRUCTIONS TO NAVIGABLE CHANNELS

This Congress strongly urges against the construction or erection of any fixed structure on or over any waterway which might possibly result in an unreasonable obstruction to navigation. We further urge that no permit for the construction or erection of such a structure be issued until a showing has been made by the applicant that such structure will not, in fact, result in an unreasonable obstruction to navigation and/or will not operate to deprive waterway users of the protection and safety afforded by such waterway.

FUNDS FOR PUBLIC WORKS PROJECTS

The navigable waterways and the water supplies of the rivers and lakes of America are the greatest natural resource of this nation.

Full and comprehensive development and maintenance of these resources is necessary to insure our national security and future economic welfare. This is a responsibility which must in large part be borne by the Federal Government.

The Congress authorizes navigation and water conservation projects only when the benefits exceed the costs. There are billions of dollars of worthwhile authorized projects patiently awaiting budgeting and appropriation of funds to begin their construction. There are many important projects now under construction suffering from "stretchout" procedures, which means insufficient funds budgeted and appropriated each year to make possible early completion.

This Congress is of the opinion:

1. That it is to the general benefit of the nation that a greater percentage of the national income be devoted to development of these natural resources.

2. That a much greater number of authorized projects be budgeted and appropriations made for beginning of their construction.

3. That the agencies of the Federal Government and the Bureau of the Budget should initiate a policy, and make every effort to carry it through, of scheduling completion of projects on the basis of sound construction practice and not on the basis of pessimistic anticipation of low annual allocation and appropriation of funds for such projects.

Such a practice would decrease the cost of interest during construction and hasten the day when the benefits of the project would begin to return to the Government and local interests.

That a copy of this resolution be forwarded to the Chief of Engineers, the Bureau of Reclamation, the Bureau of the Budget and the Appropriations Committees of the House and Senate.

ACQUISITION AND USE OF LANDS BY THE UNITED STATES

It has been called to the attention of the National Rivers and Harbors Congress that problems exist in various parts of the country concerning the policies and procedures involved in the acquisition and utilization of land by the United States of America and particularly in connection with water resource development projects or Government installations adjacent to such projects.

It is the desire of the Congress to assure

1. Equitable treatment to those displaced by water resource development projects; and

2. Full exploitation of the recreation potential of water resource development projects by providing ready access to the surface of the water; therefore

I. The Congress of the United States should enact legislation to establish a commission to inquire into the policies and procedures employed in establishing just compensation for the taking of property for public use as guaranteed by the Fifth Amendment to the Constitution of the United States and to make recommendations for further legislation, if any, that may be necessary to assure equitable payments to owners and tenants displaced by public works projects of the United States and reimburse them for their actual losses.

II. The Congress of the United States and the heads of the Executive departments and agencies involved should cooperate to establish a land acquisition schedule that will provide for the acquisition of required lands at the earliest possible date after authorization of a project in order to assist those affected in minimizing their losses and in obtaining available relocation sites.

III. The heads of the Executive departments and agencies controlling lands along the shoreline of Federal water-resource development projects should provide ready access to the public of water areas thereof, either directly or through arrangement with State and local agencies for recreational development, whenever such use is determined by the head of the Department or agency involved to be compatible with the Government's use of the water area and adjacent lands.

(Submitted to the Convention and Unanimously Adopted)

NATIONAL RIVERS AND HARBORS CONGRESS

47th NATIONAL CONVENTION

WASHINGTON, D. C.

May 24-26, 1960

Report of

COMMITTEE ON INDUSTRIAL AND MUNICIPAL WATER USE AND POLLUTION ABATEMENT

The Committee reviewed its report adopted at the Annual Convention of the National Rivers and Harbors Congress held May 15, 1959, and reaffirmed the broad and constructive principles for development of adequate water supplies set forth therein, emphasizing particularly the need for constructive policies relating to conservation, municipal and domestic use, pollution abatement, flood control, irrigation, industrial use and other beneficial purposes.

The Vice Chairman, presiding in the absence of the Chairman, invited the attention of the Committee to the fact that H. R. 3610, although passed by the Congress, as urged by the National Rivers and Harbors Congress, had been vetoed by the President and that the veto had been sustained. This Bill, the Vice Chairman noted, would have increased Federal financial assistance to communities for pollution abatement projects:

The Vice Chairman further brought to the notice of the Committee the fact that the President's Budget requested only $20,000,000 to implement the grants-in-aid provisions of Public Law 660 for community pollution abatement projects but that the House Appropriations Committee had recommended the maximum amount authorized by law for this purpose.

The Vice Chairman referred also to the extensive studies and hearings being conducted by the Senate Select Committee on National Water Resources in the field of water resources development, including pollution abatement and industrial and municipal water use, and noted that preliminary releases and reports were highlighting the growing seriousness of the stream pollution problem and the vastly increasing requirements for water use, projecting water requirements by 1980 about double present levels.

The Vice Chairman further informed the Committee that pollution of the Potomac River in the Washington Metropolitan area is a problem of growing urgency but that pending legislation before the House Public Works Committee would authorize Federal assistance to the District of Columbia in the form of grants-in-aid to permit completion of an urgently needed system of interceptor sewers by the Federally-established 1966 time limit.

Reports from representatives of various parts of the country presented dramatic evidence of growing water problems. It is clear that the population of the United States will continue to grow rapidly, that the needs of industry, agriculture, and the general public for adequate supplies of water will continue to mount; and that the growth of industry and population will aggravate and intensify the already serious pollution abatement problem confronting the Nation. Accordingly, the Committee reaffirms its conviction that all uses of water are interrelated and are of concern to the public generally, and that conservation, control and equitable disposition of our water resources are matters of profound interest to the development of the national economy and the welfare of all the people. It is evident that

the water problem will become as vital to the national interest in 10 years as the missile program is today. Clearly, also the increasing pressures of various public demands for water use urgently require long range planning and effective coordination to assure maximum realization of the public values inherent in our precious water resources.

In view of the growing importance of water resource development, the following resolutions were unanimously adopted:

RESOLVED:

1. That the Committee records its regret that the President's veto of H. R. 3610, providing increased financial assistance to communities for pollution abatement projects, was sustained and urgently recommends that similar legislation be enacted at the next session of Congress.

2. That the Committee recognizes the primary responsibility of local and state governments in the field of pollution abatement but further recognizes the Federal interest in this area and, accordingly, recommends strengthened Federal procedures to supplement local, state and regional efforts to deal with this pressing problem.

3. That the Committee records its disappointment in the grossly inadequate request of only 20 million dollars in the President's Budget to implement the provisions of Public Law 660 for Grants-in-aid to communities for pollution abatement projects but strongly commends the House Appropriations Committee for recommending appropriation of the maximum amount authorized by law for this purpose and urges speedy action by the Senate on the Health, Education and Welfare Appropriations Bill.

4. That the Committee records its vigorous support and approval of the diligent efforts of the Senate Select Committee on National Water Resources to develop full information looking toward formulation of water resources policies adequate for growing national needs; urges full cooperation by the National Rivers and Harbors Congress with the work of the Senate Select Committee and urges that most careful and sympathetic consideration be given by the National Rivers and Harbors Congress to the recommendations of the Senate Select Committee upon issuance thereof.

5. That the Committee renews its expression of deep concern regarding the long continuing pollution of the Potomac River in the District of Columbia region and reaffirms its conviction that sanitation standards in the area of the Nation's Capital should set a standard for the world and that the polluted condition of the Potomac River in the District of Columbia metropolitan area demands immediate and constructive action by the Federal Government; that the Committee notes with gratification that a satisfactory plan for dealing with the problem has been evolved as a result of an enforcement conference held under Public Law 660 and that as a first step improvements in the Blue Plains Sewage treatment plant have been completed; that the Committee is strongly of the opinion that additional elements of the plan involving construction of a system of interceptor sewers should be promptly undertaken and to that end recommends support of legislation now pending before the House Committee on Public Works which authorizes appropriation of funds in the form of grants-in-aid to the District of Columbia to enable the District to complete the interceptor sewer project by the Federally-established 1966 time limit; that to expedite action on this legislation the committee urges the Bureau of the Budget to comply promptly with the request of the House Committee on Public Works for a report on appropriate means for financing this project.

6. That the Committee records its continued adherence to the principle that provision be made for storage in reservoir projects to increase needed low flows downstream to the extent warranted at present or during the economical life of the project, without reimbursement, where the benefits of such low flows are widespread, general and non-exclusive.

7. That the Committee recommends improved coordination among the agencies at all levels of Government for the more effective development and use of water resources.

8. That the Committee recommends a more adequate program to ascertain, assemble and disseminate in useful form basic data relative to surface and ground water resources; and

9. That the Committee recommends that the National Rivers and Harbors Congress investigate the feasibility of public information programs by radio, television and other means to bring before the public the growing seriousness of stream pollution and of increasing water use requirements emerging from rapid industrial expansion and population growth clearly foreshadowed for the remaining decades of this Century.

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COMMITTEE ON INDUSTRIAL AND MUNICIPAL WATER USE AND POLLUTION ABATEMENT

CHAIRMAN

REPRESENTATIVE JOHN A. BLATNIK, Chisholm, Minnesota

SECRETARY

WILLIAM J. HULL, Legislative Representative, Ohio Valley Improvement Assn., Washington, D. C.

MEMBERS

NEW ENGLAND DIVISION:

Walter G. White, Chairman, Water Resources Board, State of New Hampshire, Concord, N. H.

NORTH ATLANTIC DIVISION:

George R. Shanklin, Chief Engineer, Division of Water Policy and Supply, State of New Jersey, Trenton, N. J.

SOUTH ATLANTIC DIVISION:

Miles J. Smith, Vice Chairman, North Carolina Board of Conservation and Development, Salisbury, N. C.
Harry H. Saunders, Vice President, St. Joe Paper Co., Port St. Joe, Fla.

SOUTHWESTERN DIVISION:

Judge J. E. Sturrock, General Manager, Texas Water Conservation Assn., Austin, Tex.; Vice Chairman

LOWER MISSISSIPPI VALLEY DIVISION:

Leonard N. White, Engineer, Arkansas Geological and Conservation Commission, Little Rock, Ark.
Calvin T. Watts, Assistant Director, Department of Public Works, State of Louisiana, Baton Rouge, La.

NORTH CENTRAL DIVISION:

P. W. Fitzpatrick, President, St. Paul Port Authority, St. Paul, Minn.

MISSOURI RIVER DIVISION:

Milo W. Hoisveen, Chief Engineer, North Dakota Water Commission, Bismarck, No. Dak.

OHIO RIVER DIVISION:

Laban P. Jackson, Commissioner of Conservation, State of Kentucky, Frankfort, Ky.

NORTH PACIFIC DIVISION:

Marshall N. Dana, Chairman, Commission of Public Docks, Portland, Oregon.

SOUTH PACIFIC DIVISION:

Walter G. Shulz, Division Chief Engineer, Division of Design and Construction, Department of Water Resources, State of California, Sacramento, Calif.

REPORT

of

Committee on Irrigation and Reclamation

of the

NATIONAL RIVERS AND HARBORS CONGRESS

47th National Convention

May 26, 1960

CHAIRMAN

CONGRESSMAN, J. Edgar Chenoweth, Colorado

NATIONAL RIVERS AND HARBORS CONGRESS

COMMITTEE ON IRRIGATION AND RECLAMATION

CHAIRMAN: Representative J. Edgar Chenoweth, Colorado

VICE CHAIRMAN: J. W. Grimes, Pierre, South Dakota

SECRETARY: Ival V. Goslin, Salt Lake City, Utah
Chief Engineer & Secretary, Upper Colorado River Commission

MEMBERS

Arizona	Representative Stewart L. Udall, Tucson; Member, Interior and Insular Affairs Committee
California	Representative B. F. Sisk, Fresno, California; Member, Interior and Insular Affairs Committee
Colorado	Representative Byron G. Rogers, Denver Harold H. Christy, Pueblo; Director, National Reclamation Association
Idaho	George L. Crookham, Jr., Caldwell; President, Guffey Water Development Association
Kansas	Robert V. Smrha, Chief Engineer, Division of Water Resources, State Board of Agriculture, Topeka
Montana	Everett W. Rising, Washington Representative, State Water Board of Montana
Nebraska	Pete Badura, Ashton; President, Farwell Irrigation District
Nevada	Representative Walter S. Baring, Reno; Member Interior and Insular Affairs Committee
New Mexico	John P. Murphy, Albuquerque; Secretary, New Mexico Reclamation Association
North Dakota	Fred Frederickson, Valley City; Washington Representative Greater North Dakota Association
Oklahoma	Frank Raab, Oklahoma City, President, Canton Irrigation District; Represented by Guy H. James
Oregon	Representative Al Ullman, Baker; Member Interior and Insular Affairs Committee
South Dakota	J. W. Grimes, Pierre, South Dakota State Engineer
Texas	Kenneth M. Smith, McAllan; Water Master, Lower Rio Grande
Utah	T. W. Jensen, Salt Lake City; Secretary Utah Water Users Association
Washington	John Richardson, Olympia, Wash.; Supervisor Department of Conservation & Development
Wyoming	State Senator Earl T. Bower, Worland

REPORT

of

COMMITTEE ON IRRIGATION AND RECLAMATION

INTRODUCTION

The Committee on Irrigation and Reclamation of the National Rivers and Harbors Congress was convened for the first time at the 44th Annual Convention three years ago. Since that time the Committee has continued to function and to maintain a high level of interest and participation in the irrigation and reclamation program of the United States.

During January of 1960 efforts were made to hold an extra session of the Irrigation and Reclamation Committee for the purpose of reviewing the Federal reclamation program and making recommendations relative to it to the United States Congress. Because it became apparent that it would not be practicable to have a majority of the Committee members present at such a meeting these efforts had to be abandoned.

Purposes of the Irrigation and Reclamation Committee

This Committee has been directed to deal only with matters of general policy.

At its inception the purposes of this Committee were defined as the formulation of a policy and a program for the continued, orderly development by reclamation and irrigation of our water and land resources in the arid and semi-arid regions of the West, and to suggest ways and means whereby the National Rivers and Harbors Congress may better cooperate and coordinate its efforts with the advocates of reclamation and irrigation.

Committee Personnel

The personnel of the Committee on Irrigation and Reclamation are listed on Page 1 of this report. This Committee is interested not only in irrigation and reclamation, but in flood control projects, rivers and harbors projects, and, in fact, all phases of water resource development.

PROGRESS

In this Committee's report for 1957 to the National Rivers and Harbors Congress, several policy and procedural recommendations were outlined. These were designed as guides and suggestions for implementing basic principles. The adoption of these recommendations by this organization has contributed greatly to a better understanding of water resources problems. It is gratifying to note that sponsors of projects are recognizing new possibilities for

coordination of efforts and cooperation in developing water and land resources. This new spirit and its resultant accomplishments constitute progress--not because during the past year we feel that the program of project development has been accelerated to the point necessary or desirable--but because future results will prove the wisdom of united efforts.

As a result of cooperative efforts, Congress enacted a Public Works Appropriation Bill for fiscal 1960 that contained many unbudgeted water development projects, of which seven were major reclamation "new starts." In addition, four were initiated under the Small Reclamation Projects Act, P.L. 984, and two were loans for irrigation distribution systems under P.L. 130.

RECLAMATION IS A VITAL PART OF AMERICA'S FUTURE

Our Committee concurs with the Hon. Wayne N. Aspinall of Colorado, Chairman of the Interior and Insular Affairs Committee of the U. S. House of Representatives, who said to the House Appropriations Committee, "..... the continued development of supplemental water supplies for existing irrigated areas and the opening of new lands to settlement through Reclamation are entirely consistent with sound, long-term agricultural objectives. Such development provides the most important basic element to a successful regional economy--a stable, diversified agriculture. In addition to improving our existing agricultural situation, Reclamation helps to insure adequate future food and fiber for our rapidly growing population.

"The objective of expanding the economy of the West is of prime importance to the whole Nation. The Federal Reclamation program has been one of the important tools by which the underdeveloped arid and semiarid regions of the West have been made into a habitable and productive part of the Nation by promoting westward movement of population, business, and agriculture, and providing a solid base for investment and employment where little existed previously. The Reclamation program still has these positive influences today.

"With respect to my statement that Reclamation tends to alleviate the existing imbalances of agriculture, I have this to say. It is not widely understood that irrigation farming in the West enjoys a complementary, rather than competitive, relationship with the whole of the country's agriculture. Of the major crops in surplus, those that constitute more than four-fifths of the holdings and loan commitments of the Commodity Credit Corporation, Reclamation farms grew only three of these crops, and the 1958 contribution from Reclamation farms amounted to only 1.8 percent of the holdings. The reason why this proportion is so small when the total importance of Reclamation in the economy of the West is so great is that the irrigation farmer has been able to shift production from surplus crops to those that are in current demand. The non-irrigated land is largely tied to a one-crop economy and cannot diversify in response to changing demand patterns. Reclamation has played a large role in facilitating these adjustments and in enhancing the efficiency of the agriculture of the West as a whole. The misapprehension that any extension of irrigation will compound the Nation's agricultural difficulties is not borne out by the facts, either past or present.

"In addition, we are advised by agricultural authorities that our present crop imbalances are merely temporary and that continued efforts are needed in research and the conservation and development of soil and water resources. They emphasize that the capacity to meet the food and fiber needs of the expanding population does not happen automatically. Because major irrigation projects do not reach a fully developed stage until 15 to 25 years after authorization or start of construction, it is essential that Reclamation needs be viewed in future perspective.

"The Nation's population is increasing at about 8,600 additional persons per day while the acreage of good cropland diminishes at a rate of 3,000 acres per day due to conversion to roads, airports, and cities. Just how soon our agricultural abundance will give way to shortages depends on what positive steps are taken to overcome the efforts of these incursions."

Senator Allen Ellender of Louisiana said at a dinner sponsored by the National Association of Soil Conservation Districts honoring the 25th anniversary of the Soil Conservation Service:

"It is interesting to note that these additional mouths must be fed; these additional bodies must be clothed, these additional people housed from substantially fewer acres than are now available for cultivation. The fact is we have no new land to bring into cultivation. All we have is land which we can improve.

"Yet, each year we are losing precious irreplaceable soil and water resources due to the encroachments of urban population areas, among other things. Specifically, by the year 2,000 some 80 million additional acres of our very finest cropland will be lost to creeping urbanization. Against this 80 million acre loss we can count, on the plus side of the ledger, only about 25 million acres, which we hope to add to our production base during the same period of time. The difference, that is 55 million acres, must be derived from increased productivity--by producing more food and fiber from the same acreage which we cultivate today."

RECLAMATION - KEY TO THE FUTURE

Reclamation is the key to the future. It is a real American enterprise that unlocks the doors to opportunities in industry and business. Reclamation is not to be considered only in terms of agricultural development. Recognition must be given to the industrial and business economies that are directly dependent upon and inevitably follow the development of an irrigated agricultural project.

A productive agricultural economy and the availability of water for domestic and industrial uses, made possible by reclamation, are essential to provide for our expanding populations. Agriculture and industry are complementary.

Reclamation projects are providing millions of Americans with opportunities for recreation and constructive use of an increasing amount of leisure time in a world filled with nervous tensions. Immeasurable as these recreation

values may seem, they are real values and contribute greatly to both physical and mental health and productive potential in many vocations. In 1959 the visitor count at reclamation reservoirs of the 17 Western States reached the astounding total of 22,700,000.

Only through continuing the development of our water resources can our Nation meet the future needs of its citizens.

The Reclamation program has proved to be an economically sound and financially feasible enterprise for the Federal Government. Every four years the value of crops produced on Reclamation farms equals the total money appropriated for Federal Reclamation since its inception 58 years ago. The cash value of the crops produced in 1958 was almost $1 billion. Since the Reclamation Program was initiated in 1902, $14,265,102,000 worth of crops have been produced. The Federal Government has received nearly $3,900,000,000 in federal taxes derived from Reclamation projects and adjacent trade areas since 1902.

From a financial standpoint, Reclamation projects repay the investment in many ways besides repaying to the United States all of the costs allocated to irrigation features without interest and the costs allocated to power and municipal water supplies with interest. Reclamation portions of Federal multiple-purpose developments create economic returns in the form of stabilized downstream flows for industrial waters, pollution abatement, and other benefits that are not reflected in the financial feasibility of irrigation use of water. Western Reclamation projects develop flood water as the irrigation water supply, thereby accomplishing flood control as an important by-product.

IMPORTANT CURRENT PROBLEMS

1. Criteria For Evaluating Water Development Projects

There is a definite need for the formulation of modern, consistent and realistic general principles to guide Federal agencies in analyzing and appraising potential water development projects. The National Rivers and Harbors Congress can do a real service to future progress by urging the United States Congress to establish the policy to be followed by Federal agencies in the evaluation of project benefits.

2. Protection Of Water Rights Acquired Under State Laws

For many years efforts have been made to persuade Congress to enact legislation that would protect owners of water rights acquired in the various states against the encroachment of Federal agencies. These efforts have been largely unsuccessful. There are several bills for this purpose pending before the United States Congress. It is the consensus of our Committee that the National Rivers and Harbors Congress should join the campaign to inform our legislators of the importance of enacting a States Water Rights Bill that will accomplish the desired purpose of protecting water rights vested under State laws.

RECOMMENDATIONS

The following recommendations embody principles essential to a well-rounded yet progressive irrigation and Reclamation program to be correlated with and complementary to a national program of development, utilization and conservation of our Nation's water resources.

It is recommended that:

(1) Where opposition to water development programs exist, officers, members of, and delegates to, the National Rivers and Harbors Congress should act without delay to neutralize such opposing influences with any effective means available at local, state and national levels.

(2) Authorization and construction should not be subjected to a "stop-and-go" policy. Funds for Reclamation portions of multiple-purpose developments should be increased and maintained at a level that would be consistent with the annual gross national product.

(3) The Congress of the United States should establish the policy and criteria under which all Federal water development projects will be authorized and constructed.

(4) On multiple-purpose projects, wherever practicable, the development of water resources should be preceded by basin-wide planning.

(5) Power revenues derived from Federal projects should be used on a basin-wide or area-wide basis to assist in repayment of irrigation allocations on Federal projects.

(6) The principle of the Interstate Compact should be encouraged in order to avoid litigation between and among States and to preclude domination of the development and control of natural resources by Federal agencies.

(7) Procedures under which Federal water resources projects are investigated and reported should be simplified.

(8) Criteria under which Federal agencies evaluate water resource development projects before submitting them to Congress for authorization or construction should be reviewed and re-established to include consideration of all future benefits.

(9) Basic land and water inventories, soil and water research, snow surveys and stream forecasting should be continued, expanded and modernized in order to provide adequate data for current and future planning.

(10) The use of conservancy-type districts capable of levying taxes on project beneficiaries as agencies to execute repayment contracts with the Federal Government should be encouraged in order to more equitably allocate costs of a project and meet the burden of expensive and complex project construction.

(11) In planning and constructing water resource projects the principle of supplying supplemental water to lands presently inadequately irrigated should be given priority over bringing new lands into cultivation.

(12) It is further recommended that the National Rivers and Harbors Congress, through its executive offices and appropriate committees:

a. Accelerate its campaign in support of a water-utilization program designed to fully develop our land and water resources placing special emphasis on starting new water development projects that are financially feasible and economically justified;

b, Continue to bring to the attention of the Executive and Legislative Branches of our Federal Government the need for a continuous, progressive, planned program of project authorization;

c. Urge and actively support adequate appropriations for investigating and planning conservation water-use projects;

d. Support legislation requiring compliance with and adherence to State Water Laws by Federal Agencies.

e. Support legislation to require Federal agencies to employ more liberal and realistic criteria in their evaluation of water development projects prior to authorization and construction.

SUMMARY

In summary, the purposes of the Committee on Irrigation and Reclamation of the National Rivers and Harbors Congress shall be to promote the development, control, conservation and utilization of the Nation's water resources, to work for the continuation of the services and the coordination of activities of Federal agencies dealing with water resources, to cooperate with and assist in securing authorization and construction of Federal conservation water-use projects which meet with the approval of States and local agencies, to assist water users of the Nation in the economic development of river basins, to preserve the rights and interests of the States in their water resources, to promote the enactment of legislation favorable to these principles.

* * * * * * * *

The Committee on Irrigation and Reclamation unanimously approved the foregoing statement and recommends that it be adopted by the National Rivers and Harbors Congress.

Ival V. Goslin
-Secretary-

The Committee on Wildlife and Recreation was called to order by Chairman Ed Edmondson at 10:30 a. m., Tuesday, May 24, 1960, in the Concord Room of the Mayflower Hotel, Washington, D. C.

The following members of the committee were present: Chairman, Representative Ed Edmondson; Ronald W. Green, Augusta, Maine; Hayden W. Olds, Columbus, Ohio and W. D. H. Rodiguez, Monroe, Louisiana. Arthur S. Tidwell, Jr., Monroe, Louisiana, was appointed to the committee by the Chairman and thereafter elected secretary by the committee. Committeeman John A. Biggs, Washington State, entered the committee meeting after noon, along with Senator Leon Field and W. T. Gooldy, Oklahoma, representing Committeeman George Knapp, Oklahoma.

The meeting adjourned at noon and convened again at 2:30 p. m. and adopted the following resolutions:

1. To commend the President and the Executive Officers of the National Rivers and Harbors Congress for creating the Committee on Wildlife and Recreation thereby recognizing the importance thereof to the public welfare of the nation and permitting greater consideration of these subjects in the deliberations of the National Rivers and Harbors Congress.

2. To support and endorse Federal legislation designed to recognize recreation as an integral part of any new flood control legislation, water supply, hydro-electric or reclamation project and that recreational benefits be evaluated and considered as a partial justification for such projects.

3. To request consideration of a change in the present land acquisition policy of the Federal Government to promote the acquisition of an adequate acreage in fee simple to guarantee public access and use for recreational purposes and that the cost of these lands be included as a part of the project cost.

4. To request consideration of the development of recreational and access facilities as part of the cost of approved projects.

5. To endorse, approve and urge the continuance of the present policy under which the United States Corps of Engineers and the Bureau of Reclamation make available recreational areas under lease or license to state and political sub-divisions, civic and service non-profit organizations.

6. To preserve and protect the recreational and wildlife facilities we urge the continuation of the Federal anti-pollution control program and the provision of matching funds to finance this program.

The meeting was adjourned at 4:30 p. m.

THE COMMITTEE UNANIMOUSLY RECOMMENDS THE ACCEPTANCE OF THESE RESOLUTIONS BY THE CONGRESS OF RIVERS AND HARBORS.

FOR RELEASE WHEN READ

REPORT OF THE PROJECTS COMMITTEE
TO THE
47th NATIONAL CONVENTION
OF THE
NATIONAL RIVERS AND HARBORS CONGRESS

May 26, 1960

Mr. Henry H. Buckman, President
National Rivers and Harbors Congress
Washington, D. C.

Dear Mr. President:

In pursuance of the call of the President, your projects committee met on May 24, 1960, to consider the projects submitted since the last session of the National Rivers and Harbors Congress. Hearings were afforded all who made appearance.

The Committee at this session has examined 69 proposals embracing all resource improvements with which this Congress is concerned, including navigable waterways, harbors, flood control, hurricane protection, soil conservation, reclamation and water conservation.

Of the proposals examined, this committee is convinced that 21 constitute projects sound in conception, needful, and sufficiently advanced in status to warrant endorsement, involving a total estimated cost of $284,440,400. Thirteen proposals appear to be without sufficiently advanced development to warrant project endorsement at this time, but are believed to be meritorious and entitled to further consideration by this committee, if and when additional information may be

adequate to warrant an endorsed status. We find that on 30 proposals, surveys have been authorized but the reports of said surveys have not been completed and we therefore recommend in these cases that the Congress request the appropriate authority to complete reports of its investigations and surveys as soon as practicable in order that action may be taken toward classification by this Congress. We find five proposals which on preliminary examination appear to be desirable and needful, and we accordingly recommend that engineering and economic investigations of survey scope be made in these cases with a view to developing projects for subsequent authorization.

Appendix A of this report sets forth in detail a list of all proposals and projects examined and the action taken thereon.

At the present time, the Congress of the United States is considering enactment of an omnibus river and harbor and flood control bill. The Committee on Public Works of the House of Representatives held public hearings on various river and harbor and flood control projects previously submitted to the Congress by the Secretary of the Army. At the conclusion of the hearings an omnibus bill, H. R. 7634, was favorably reported by the Committee on June 12, 1959, and passed by the House of Representatives on July 16, 1959. A summary of the authorization contained in the bill as it passed the House is as follows:

Title I. Rivers and Harbors:

Sec. 101:	
36 - Navigation projects	$ 86,581,500
2 - Beach Erosion Control Projects	371,300
1 - Monetary authorization (Barkley Dam, Ky.)	146,000,000
Total Title I	$ 232,952,800

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Total Title I	$	232,952,800

Title II. Flood Control

Sec. 201:		
10 - New projects or project modifications	$	45,357,700
7 - Increased basin authorizations		379,000,000
Total Title II	$	424,357,700
Grand Total	$	657,310.500

The Committee on Public Works of the United States Senate held public hearings on August 4 and 21, 1959. Additional public hearings were held on April 19, 20, 21, 25 and 26, 1960. Approximately 60 projects not included in the House-passed version of the bill were heard by the Senate Committee. Also, increases in river basin monetary authorizations are being considered. It is expected that action on the bill will be taken by the Senate in the near future .

The projects included in the pending bill are of great importance to the Nation's expanding economy and should be provided at the earliest practicable date. Your Projects Committee recommends that the Congress of the United States be requested to take early action on the Bill and that consideration be given to early appropriation of funds for construction of these proposed projects.

Since our meeting a year ago, serious floods have occurred throughout the nation. most notably in the Missouri and upper Mississippi River Basins, and on major streams in New England, Georgia, Alabama, and Florida. The human suffering and costly damages caused by these floods are dreadful reminders that much needs to be done to control the waters of our rivers.

While the regulation of the high flows of rivers to prevent floods is urgent at the present time, the need for regulating rivers for all purposes becomes more and

and more evident as time goes on. The recent succession of drought years in the Southwest, the crowding of industry to river banks in search of water and economic bulk transportation and the increasing pollution of our rivers indicate the soundness of developing our water resources for all purposes. Your committee notes the trend in this direction indicated by actions of the Congress of the United States, and indorses this concept.

Much also needs to be done to improve our inland waterways, so that the needs of our increasing population and the resulting expanding economy can be adequately fulfilled. New industries are constantly in search of sites offering economical bulk transportation, and the most promising sites are consequently those located on improved waterways. The St. Lawrence Seaway, recently opened to deep-draft navigation, is producing great benefits to both local and national economies; similar benefits can also be realized elsewhere, on a smaller scale perhaps, but none the less important. We must not relax our efforts to give our waterways improved to the end that the industrial growth necessary to our economy can take place in a steady and orderly manner.

Your Committee notes that the backlog of investigations authorized by Congress for prosecution by agencies of the Federal Government is at least as large this year as it was last year. These investigation programs are important first steps toward the authorization and construction of urgently needed improvements. We urge that the appropriations for this purpose be increased substantially.

Respectfully submitted,

PHIL WEAVER,
CHAIRMAN

Note A - A project which has been placed in Class II, III, IV or V by the Committee may be re-examined from time to time upon due application and the submission of material supplementary information, with a view to advancing its classification; but no project will be reported upon by the Committee more than once in each year.

Note B - Attention is called to the fact that when a project is once put in Class I - Endorsed, such status continues and it is unnecessary to follow up at subsequent sessions with new applications. All projects "Endorsed" by the Congress, upon the recommendations of the Committee retain their status until finally constructed, unless such action is rescinded by the Congress, and the Congress stands pledged to do everything possible to assist in reaching that goal.

APPLICATIONS FOR APPROVAL OF PROJECTS
RECEIVED BY
THE PROJECTS COMMITTEE

APPENDIX A

(Letter "R" following the project number indicates revision of a previous application)

Division I - Endorsed

Endorsed. This means that it is the judgment of the Committee that the project is sound, needful and sufficiently advanced in status; and that its construction is justified by the public interest it will serve.

Docket No.	Name of Project	State or States	Division
981-R	Huntington Reservoir	Ind.	O. R.
1063-R	Monroe Reservoir	Ind.	O. R.
1090-R	Hurricane Flood Protection of Pawcatuck	Conn.	N. E.
1107 - R	Abatement Works for the District of Columbia, Project "C"	D. C.	N. A.
1138-R	Mississinewa Reservoir	Ind.	O. R.
1139	Municipal Commercial Harbor at Dubuque on Upper Mississippi River (Dredging)	Iowa	N. C.
1140	North Branch Park River Watershed Protection and Flood Prevention Project	Conn.	N. E.
1141	Matagorda Ship Channel	Texas	S. W.
1142	Little Dell Reservoir-Jordan River Basin - Salt Lake City Streams	Utah	S. P.
1143	Flood Control Project on the Mississippi River at Saint Paul & South St. Paul	Minn.	N. C.

Division I (continued)

Docket No.	Name of Project	State or States	Division
1144	Fairport Harbor	Ohio	N. C.
1145	Curwensville Reservoir, West Branch, Susquehanna River	Pa.	N. A.
1147	Millers Ferry Multiple-Purpose Dam, Alabama-Coosa River System	Ala.	S. A.
1148	Salamonie Reservoir	Ind.	O. R.
1149	Trinity River, West Fork Watershed, Flood Protection, Fort Worth Area	Texas	S. W.
1150	Big Fossil Watershed, Trinity River and Tributaries	Texas	S. W.
1151	Richland, Chambers and Cedar Creeks (Waxahachie Creek Watershed), Bardwell Reservoir	Texas	S. W.
1152	Levee Unit 5; Wabash & Patoka Rivers	Ind.	O. R.
1153	Mississippi River-Gulf Outlet, Crossing for State Highway No. 47 (Paris Road) High-Level Fixed Bridge	La.	L. M. V.
1176	Stamford Hurricane Protection	Conn.	N. E.
1178	Trinity River & Tributaries, (Wallinsville Reservoir)	Texas	S. W.

Division II

Meritorious

Meritorious. This means that the committee believes that although the project is not sufficiently advanced in status to warrant its present endorsement, it is meritorious and that the committee is willing to consider in due course, its advancement to Division I upon presentation by its sponsors of additional evidence justifying such action.

Docket No.	Name of Project	State or States	Division
793-R-7	Flood Protection, Cleves	Ohio	O. R.
1094-R-1	Rend Lake	Ill.	L. M. V.
1100-R-2	Wilmington Harbor	N. C.	S. A.
1109-R	Columbia & Lower Willamette River Deep Draft Ship Channel	Ore. & Wash.	N. P.
1114-R-2	Flint River Channelization, Flood Control, Hydro-electric	Ga.	S. A.
1154	St. Marks River Project	Fla.	S. A.
1164	Rouge River Flood Control	Mich.	N. C.
1166	Las Vegas Wash and Tributaries, Las Vegas and Vicinity, Flood Control	Nev.	S. P.
1183	Trexler Dam and Reservoir	Pa.	N. A.
1184	Tocks Island Dam and Reservoir	Pa. & N. J.	N. A.
1185	Prompton Dam and Reservoir	Pa.	N. A.
1186	Beltzville Dam and Reservoir	Pa.	N. A.
1187	Blue Marsh Dam and Reservoir	Pa.	N. A.

Division III

Expeditious Report on Authorized Survey Requested

Expeditious report on authorized survey requested. This means that the committee believes that the National Rivers and Harbors Congress should request the engineering authority to expedite any report on any authorized investigation or survey of the project to the end that appropriate further action may be had thereon in regard to its classification.

Docket No.	Name of Project	State or States	Division
876-R-5	Whitewater River, West Fork Brookville	Ind.	O. R.
1092-R	Passaic River Basin, Flood Control	N. J.	N. A.
1096-R-2	Harbor Development, Port San Luis	Calif.	S. P.
1126-R	Norfolk Harbor and Channel to Newport News	Va.	N. A.
1128-R	Imperial Beach Small Craft Harbor (Oneonta Lagoon)	Calif.	S. P.
1134-R	East Fork Reservoir; East Fork, Little Miami River	Ohio.	O. R.
1140-A	Shelter Cove Harbor	Calif.	S. P.
1146	Duwamish Development Project	Wash.	N. P.
1155	East Pass Channel at Destin	Fla.	S. A.
1156	Small-boat Channel from the Port of Panacea into Apalachee Bay	Fla.	S. A.
1157	Waikiki Beach Improvement (Kuhio Beach Improvement and Widening of Sidewalks)	Hawaii	P. O.

Division III (Continued)

Docket No.	Name of Project	State or States	Division
1158	Iao Stream Flood Control Project	Hawaii	P. O.
1159	Wailoa Stream	Hawaii	P. O.
1160	Waimea River, Kauai	Hawaii	P. O.
1162	Kihei District, Maui	Hawaii	P. O.
1163	Palolo and Manoa Valleys	Hawaii	P. O.
1165	Trenton Channel Extension (to deep water in Lake Erie), commonly referred to as "All American Channel"	Mich.	N. C.
1167	Rouge River Harbor Development	Mich.	N. C.
1168	Haleiwa Beach Erosion Project	Hawaii	P. O.
1169	Honolulu Harbor - Deepening and Widening of Harbor and Channel	Hawaii	P. O.
1170	Harbors for Light-Draft Vessels - Coasts of Hawaiian Islands	Hawaii	P. O.
1171	Hilo Harbor Modification, Island of Hawaii	Hawaii	P. O.
1172	Port Allen Harbor Modification, Kauai	Hawaii	P. O.
1175	Port Jefferson Harbor	N. Y.	N. A.

Division III (Continued)

Docket No.	Name of Project	State or States	Division
1177	Hydroelectric Dam at Rampart on the Yukon River	Alaska	N. P.
1180	Boat Basins in the Apalachicola River in the vicinity of Briston and in the vicinity of Blountstown	Fla.	S. A.
1181	Channel from Lynn Haven Bayou, to North Bay	Fla.	S. A.
1182	Gulf Intracoastal Waterway from St. Marks to the Anclote	Fla.	S. A.
1188	Intracoastal Waterway - St. Marks River to Tampa Bay	Fla.	S. A.
1189	Ogdensburg West Channel Dredging	N. Y.	N. C.

Division IV

Projects Recommended for Survey

Recommended for survey. This means that the committee believes that sufficient showing on behalf of the project has been made to warrant further examination in the form of an adequate survey by an appropriate agency of the Federal Government.

Docket No.	Name of Project	State or States	Division
1127-R	Southern Branch of Elizabeth River, Norfolk Harbor	Va.	N. A.
1161	Kamuela Flood Control	Hawaii	P. O.
1173	Kahuluu Harbor, Oahu	Hawaii	P. O.
1174	Explosives Handling Facilities Within Hawaii Harbors	Hawaii	P. O.
1179	Examination and Survey, Edwards Underground Reservoir and contributing Drainage Area	Texas	S. W.

DEVELOPMENTS IN ARTIFICIAL GROUND WATER RECHARGE

TASK GROUP REPORT

A report of Task Group 2440 R of the American Water Works Association by John J. Baffa, (Chairman) Consulting Engineer, New York City. Other members of the Task Group are H.C. Barksdale, C.M. Bechert, M.L. Brashears, C.R. Compton, F.B. Laverty, A.M. Rawn, L.B. Losee, L.F. Warrick, and W.F. Welsch.

Artificial ground water recharge practices in the United States were again the subject of a biennial questionnaire circulated in 1959 by Task Group 2440 R. Replies were received from all States and the District of Columbia. Respondents included ground water representatives of the U.S.G.S., State Sanitary Engineers and State Water Control and Conservation Agencies. The Task Group has also studied legislation affecting artificial ground water recharge and all available literature issued since its previous report (1).

Appended to this report is the first chapter concerned with the technical aspects of artificial recharge. The first chapter is entitled "Purposes of Artificial Recharge". The Committee invites comments by all interested persons. Subsequent chapters will cover recharge methods, design criteria, and economics.

RECENT DEVELOPMENTS

Answers to the 1959 questionnaire indicated that:

1. Large volumes of water are being recharged to replenish ground water by artificial means.
2. Interest in artificial recharge continues unabated as evidenced by the initiation of additional experimental projects and inquiry into fundamental principles.
3. There is increased interest in the economics of artificial recharge as a water supply method.
4. There is increased interest in operating data for recharge projects.

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NATIONAL LEGISLATION

On April 20, 1959, Senate Resolution 48 was passed by the United States Senate. This resolution authorized the establishment of a special temporary committee to study water resources activities in the United States, as a basis for making recommendations to the Senate for use in considering water resources policies for the future. On the agenda of this committee is a water supply demand study which will give consideration to available ground water supplies as a means of meeting needs. Also to be included are studies of waste water reclamation. The Task Group believes that artificial recharge activity provides an economically advantageous water supply method for water catchment, water storage, water quality control, waste water reclamation and water resource protection and conservation. On this basis, current artificial recharge practices should be evaluated in the national water resource inventory.

STATE LEGISLATION

In keeping with increasing nation wide attention to regional needs with respect to water resources, the Conservation Law of the State of New York was amended by Chapter 843 of the laws of 1959. The Water Power and Control Commission was renamed to be known as the Water Resources Commission. The Commission was expanded to include the Commissioner of Health and the Commissioner of Agriculture. The Commission was also authorized to make or to have made studies of water resources on an area or regional basis.

CALIFORNIA

Artificial recharge practices in California were reported by Harvey O. Banks, Director of the Dept. of Water Resources. "Study in 1958 and 1959 showed that 55 public and private agencies oporated about 275 artificial recharge projects and planned about 30 additional projects. The figure of 275 compares with a figure of 78 projects evolved from a similar study made in 1955. The water that is spread at the major number of these projects goes into the ground water basins which are common reservoirs for domestic municipal, industrial, and irrigation supply".

"Recorded amounts of recharge in the period 1912-1913 through 1957-58 totaled about 6.25 million acre feet, of which about 640,000 acre feet occurred during the 1957-58 water year. In addition, there is a considerable amount of recharge in areas where activity in this field was reported but where no measurements of volume were made".

"A study indicated that in inland areas where sewage effluent is disposed to land, approximately 85% of the water disposed is conserved".

"Studies are in progress which consider not only the economic benefits of artificial recharge but also water quality aspects and maximum practicable utilization of local supplies. These studies indicate that in southern California, such conservation will not remove the necessity for the construction of additional facilities for the importation of water. As a consequence of this conclusion and other economic factors, studies are being made which also consider the use of ground water basins for the regulation of a portion of the supply derived from facilities which import water".

ILLINOIS

A summary of eight full seasons of recharge operations at the Peoria infiltration pits has been reported by Robert H. Harmeson, Head, Peoria Laboratory, Illinois State Water Survey Division. In eight seasons of operation 3.58 billion gallons of water have been recharged. This represents an average recharge of about 4.7 million gallons per operating day. Operating procedures have included measurements of river stage, ground water level, river temperatures, chemical constituents, applied chlorine dosage, silt tests and agar plate counts and tabulation of confirmed lactose fermentation tubes. The bacteria tests were made to control chlorine dosage. Costs of operation ranged from 2.7 cents per 1000 gallons recharged in 1954-55, 2.9 cents in 1955-56, and 1.6 cents in 1956 to 1958. Recharge operations by the State Water Survey were terminated about May 1959. It has been proposed that the operation be continued by a local corporate body at an estimated cost of two cents per 1000 gallons recharged. This cost includes a 1/2 time project Engineer, pit operators, water, electricity, gas, pit cleaning, chemicals and equipment maintenance.

WASHINGTON & OREGON

Extensive data on artificial recharge practices in Oregon and Washington have been made available by the U.S. Geological Survey in a report by Donald H. Hart (2). Nine installations are described. Purposes of recharging are to replenish supply, to conserve physical characteristics of the water or to dispose of excess uncontaminated water. In the nine installations, about 2558 acre feet per year are recharged. Of this amount 695 acre feet represent heat pump exhaust water recharge.

The Richland Washington Public Supply System utilizes the largest amount of recharge water of 12,000 acre feet per year. Of this amount 2200 acre feet are pumped from the Columbia River and the remainder is diverted by canal from the Yakima River. The Richland System uses recharge ponds; all the other operations use recharge wells. The report states, "The success to date indicates that the process will find greater use in the future".

As to the recording of operating data, the report states, "The operators have found that some operating problems arose from insufficient records of the amounts of water recharged and withdrawn and of the chemical and physical quality of the water. The study indicates that future users of artificial recharge will find it advisable to record such data regularly".

Also in the State of Washington, an evaluation of the Walla Walls City Water Supply recharge experiment has been prepared and is currently being reviewed by the U.S. Geological Survey for public release.

NEW YORK

It has been reported by Fred W. Welsch, Senior Hydraulic Engineer, Nassau County Dept. of Public Works, that under a long-range drainage and conservation program, 405 storm water recharge basins have been developed successfully in Nassau County and 400 storm water recharge basins have been developed in Suffolk County; both counties comprise Long Island in New York. It is estimated that approximately 40 million gallons per day of storm water run-off replenishes ground water storage in Nassau County at the present time. Future development of recharge facilities may ultimately increase this figure to 70 million gallons per day. The corresponding figures for Suffolk County are 10 MGD and 50 MGD respectively.

SALT WATER INTRUSION

It is reported from Florida that dams in drainage canals are operated to keep canal levels high during dry periods in order to prevent sea water intrusion in coastal areas.

The most noteworthy development since our last report has been in California. The State of California Dept. of Water Resources, Division of Resources Planning, has issued as its Bulletin No. 63, its report upon sea water intrusion in California (3). Appendix B of the report is the report by the Los Angeles County Flood Control District on Investigational Work for Prevention and Control of Sea Water Intrusion, West Coast Basin Experimental Project, Los Angeles County. These reports describe and record the extensive field and laboratory experimental activities performed in connection with this large scale project. The present status of sea water intrusion into coastal ground water basins in California is discussed, methods of control are described, experimental studies applicable to the determination of design criteria are summarized.

The report presents a great deal of data on well injection rates and hydraulic and chemical gradients in the aquifers tested. The report recommends a continuous program of study and legislation for planned utilization of ground water basins together with positive action to halt and abate sea water intrusion in all basins known to be affected and to prevent intrusion into the threatened areas.

RECLAMATION OF SEWAGE EFFLUENTS

The recharge of ground water by sewage effluents is also receiving attention. The Los Angeles County final report on the 37th month Hyperion Reclamation & Recharge Test has been prepared. Effluent from the Hyperion high rate activated sludge plant, normally discharged to the ocean, was used as a source of water. Intermittent spreading in small basins four times daily, allowing time for soil re-aeration between spreading cycles was highly effective. The biochemical oxygen demand and the suspended solids content of the activated sludge treatment effluent were reduced by 90 to 95% and produced a water meeting U.S.P.H.S. Standards for drinking water. Water treated by this method was successfully recharged through an injection well for a continuous period of 6 months. Percolation of the chlorinated reclaimed water through short reaches of aquifer following injection achieved further improvement in the organic and bacteriological quality of the water.

The City of San Bernardino, California, plans to recharge its ground water supply with sewage treatment plant effluent.

Rawn & Hedger (7) in a report to the Board of Supervisors of Los Angeles County envision a demonstration plant to provide 10 MGD for recharge of ground water.

A report of the Water Pollution Research Laboratory of the British Government indicates large scale experiments in progress to determine effects of recharging ground water supplies with treated sewage effluents.

Ongerth & Harmon (6) have discussed the sanitary engineering aspects of recharge with reclaimed sewage.

NEW PROJECTS

Milwaukee, Wisconsin, will participate in an experiment to determine whether the rock formation from which the suburb of Wauwatosa obtains its supply, can be recharged with filtered Lake Michigan water. Studies initiated by State & Local Officials as a result of accelerated lowering of the ground water levels with increased demands during World War II, indicated the practicability and potential benefits of such a program.

Kalamazoo, Michigan, in cooperation with the U.S. Geological Survey is engaged in an extensive well planned recharge experiment to study well field recharge by means of a recharge pond. Both the well field and recharge pond are alongside a stream. It is planned to increase natural recharge from the stream by means of pond and channels. Studies will include determination of hydraulic characteristics of aquifers and aquicludes, determination of amount of recharge under conditions of drawdown and equalibrium of surface water level while

pumping wells, determination of what portion of well discharge is derived from surface recharge, evaluation of long term effects of stream flow characteristics, observation of changes in mineral content and temperature and determination of natural evapotranspiration losses and changes in evapotranspiration caused by pumping under varying conditions.

Another study is reported to be in progress at Newark, Delaware, to study the feasibility of recharging ground water supplies from surface sources.

LITERATURE

Water table fluctuations induced by intermittent recharge have been analyzed and formulated by Maasland (4). The theory may be applied to problems of ground water flow through aquifers.

The zone of aeration and its relationship to ground water recharge has been discussed by Remson, Randolph, and Barksdale (5). This paper gives the results of experiments on natural recharge at Seabrook, New Jersey. Muckel (8) describes recharge methods, selection of recharge sites and infiltration and percolation experiments in San Joaquin Valley, California.

CONCLUSIONS

On the basis of data reported in the 1959 questionnaire, the Task Group concludes that developments in the last two years indicate that:

1. Artificial recharge activities comprise an important facet of the national water resource inventory.
2. Continuing experiment and research contribute to ever increasing knowledge concerning the basic principles governing the artificial recharge of ground water.

3. The economic aspects of ground water recharge indicate the availability of a water supply method of advantage where applicable.

4. Operating and cost records of recharge operations are of advantage to the operators thereof and to the profession at large.

* * *

REFERENCES

1. Task Group Report - Artificial Ground Water Recharge. Journal A.W.W.A. 50:865 July 1958.

2. Hart, Donald H. - Artificial Rechargo to Ground Water in Oregon & Washington. Unpublished, Open File Report, Preliminary, Subject to Revision, U.S. Geological Survey.

3. Bulletin No. 63 - Sea Water Intrusion in California. State of California Dept. of Water Resources.
Appendix B - Report by Los Angeles County Flood Control District on Investigational Work for Prevention and Control of Sea Water Intrusion West Coast Basin Experimental Project, Los Angeles County.

4. Maasland, M. - Water Table Fluctuations Induced by Intermittent Recharge Journal of Geophysical Research 64:549 May 1959.

5. Remson, I., Randolph, J.R. & Barksdale, H.C. - The Zone of Aeration and Its Relationship to Ground Water Recharge - Journal A.W.W.A. 51:371 March 1959.

6. Ongerth, H.J. & Harmon, J.A. - Sanitary Engineering Appraisal of Waste Water Reuse - Journal A.W.W.A. 51:647 May 1959.

7. Rawn, A.M. & Hedger, H.E. - A Report upon the Potential Reclamation of Sewage Now Wasting to the Ocean in Los Angeles County - Report to Board of Supervisors, Los Angeles County, Los Angeles, California.

8. Muckel, D.C. - Replenishment of Ground Water Supplies by Artificial Means U.S. Dept. of Agriculture, Technical Bulletin No. 1195.

TECHNICAL ASPECTS OF ARTIFICIAL GROUNDWATER RECHARGE

PURPOSES OF ARTIFICIAL RECHARGE

CHAPTER 1

ACCOMPANYING MAY 17, 1960 REPORT OF TASK GROUP 2440 R

Artificial recharge may be defined as the practice of increasing by artificial means the amount of water that enters a groundwater reservoir (1).
The purposes for artificial recharge discussed herein are those concerned with water supply problems only; although artificial recharge has application in waste disposal, secondary oil recovery and land subsidence problems.

The need for artificial recharge has been brought about by increasing demand for groundwater as a source for fresh water. In certain local and regional areas throughout the world, the withdrawal of groundwater has exceeded the natural recharge.

The specific purposes for which artificial recharge is practiced are:

1. Conservation and disposal of run-off and flood waters.
2. Supplement the quantity of groundwater available.
3. Reduce or eliminate the decline in the water level of groundwater reservoir
4. Reduce, prevent or correct salt water intrusion.
5. Store water to reduce cost of pumping and piping.
6. Store clear cool water in winter for use during the summer.
7. Obtain heat exchange by diffusion through the ground.
8. Obtain suspended solids removal by filtration through the ground.

An artificial recharge installation may serve more than one purpose. For example, in certain areas, artificial recharge not only adds water to the available subsurface supply, but is also a means of disposing of storm water run-off. In another case, artificial recharge for salt water barrier purposes is also greatly increasing the available supply of fresh water and alleviating a ground subsidence condition which has been in progress for years.

To illustrate each recharge purpose, an example of an operating or experimental installation made for that purpose will be discussed briefly.

1. Disposal and conservation of flood water - Artificial recharge has been important in Southern California for water conservation and flood control since about 1895 (1).

   In the Santa Clara Water Conservation District's project situated in the Santa Clara River Valley in California, flood waters are stored behind dams and released slowly so that the water is absorbed in stream beds and off-channel ponds. Also, water is spread over receptive orchard land (1).

   Thus, water which would otherwise be largely wasted in this semi-arid region is conserved by storage in the ground and available for useful water requirements, and a degree of control of flood waters is obtained. A number of similar installations are in operation at other locations.

2. Supplement the quantity of groundwater available - The Duhernal Water Co., situated along the South River near Old Bridge, N.J., supplemented the available groundwater from their well field by impounding water behind a dam constructed in 1930 across a stream. Thus, by spreading water and increasing the head of water over the outcropping sands recharge to the

ground water was increased over that which occurred naturally. Later low level dams constructed across small feeder streams further increased the area of water spreading.

3. Reduce or eliminate the decline in the water level of groundwater reservoirs

The most significant artificial recharge operations in the eastern United States are being carried out at numerous locations on Long Island, New York particularly in Nassau County.

With a rapidly increasing population and industrial growth, the need to protect and conserve the sources of fresh water supplies was recognized at an early date. At first definite steps were taken to prevent pollution and contamination of the streams (2).

With the increasing transition from an agricultural to an urban land use, the run-off from storm waters greatly increased. Instead of percolating into the ground, vast quantities of the run-off water was wasted to tidewaters through storm sewers. The increasing demand for water and the decreasing quantity of water percolating into the ground were causing declining groundwater levels which, if unabated, would result in serious salt water intrusion which was occurring in the heavily populated Brooklyn area at the western end of Long Island. Since 1933, the New York State Water Power and Control Commission (now Water Resources Commission) has required that water pumped from new cooling and air conditioning wells be returned to the aquifer from which it was withdrawn. In 1936 Nassau County developed and since have actively pursued a long range water conservation program. Under this program, the use of recharge basins has resulted in the return to the ground of large quantities of storm water

which otherwise would have been wasted to tidewater (2). The application of artificial recharge methods on Long Island has made a major contribution to maintenance of the groundwater level.

4. Reduce, correct or prevent salt water intrusion. As a result of groundwater overdevelopment, extensive damage caused by sea-water intrusion has already occurred in numerous groundwater basins adjacent to the coast of California (3). A comprehensive investigational program to determine the criteria for the control and prevention of sea-water intrusion, initiated in 1951, included a large scale project to investigate the hydraulic feasibility of creating a pressure ridge in confined aquifers by means of injection wells, using fresh water, and the effectiveness of such a ridge in preventing sea-water intrusion (3). One conclusion was that direct recharge or maintenance of a fresh-water ridge above sea level may be a method to prevent or abate sea-water intrusion, depending upon geological and hydrological conditions and upon the cost and quality of available supplemental water supplies for recharge (3).

5. Store water to reduce cost of pumping and piping. Large water storage facilities close to the city to supply peak demands for Amarillo, Texas, are needed. An investigation indicates it is feasible to recharge a well field near the city limits from well field several miles distant. Underground storage space is available in the aquifer due to a decline in water table level (4).

Pumping the distant wells throughout the year at a fairly constant, but lower than maximum rate would supply the city's winter demands and provide a surplus for storing in the well field near the city. Summer demands

in excess of the pipeline capacity from the distant fields would be met by pumping stored water from the nearby field. Thus, pipeline to the new distant well fields may be smaller than would be necessary if the lines were to meet peak seasonal water demands (4). Other advantages of underground storage over surface storage are: (1) No losses by evaporation, (2) virtually no construction cost in preparing the reservoir for storage, and (3) utilization of equipment at the distant well fields, which otherwise would stand idle during the winter months (4).

6. Store clear cool water in winter for use during the summer - Cool groundwater is used by the distilleries in Louisville, Ky. Increased industrial growth in their vicinity during World War II placed an additional demand on groundwater, resulting in a lowering of the water table.

   In order to provide adequate cooling water for summer use, the distilleries recharged the aquifer through their wells with clarified river water, purchased from the city during the winter months when the river water was cold then withdrew water from the wells when the river water temperature was too warm.

7. Obtain heat exchange by diffusion through the ground - Although in New York State the requirement to recharge to the ground, well water used for cooling and air conditioning, is for conservation of water; it is practical over a long period of time because the heat picked up by the water during its use is dissipated by diffusion through the ground. The degree to which the heat is dissipated depends upon the distance it travels before being pumped again.

On Long Island, New York, the temperature of recharged cooling water ranges from 2° to 20° F. higher than that of the water pumped from the ground. This has raised the groundwater temperature appreciably in recharge centers, but where wells are not closely spaced or are separated by impervious layers, there has been no serious rise in temperature (1).

8. Obtain suspended solids removal by filtration through the ground - Recharge from induced filtration by pumping wells located near surface sources will illustrate this purpose.

A war industry plant located near Charleston, Indiana, on the Ohio River had need for large quantities of water, a sizeable amount of which had to be clear water. Investigation showed the glacial outwash sands and gravels underlying the land terrace along the river were hydraulically connected with the river from which large quantities of water could be induced by pumping water from the glacial materials. Consequently, several Ranney type radial collectors were installed. Not only was this an economical method to obtain the needed water, but was also clear, as the turbidity in the river water was removed by the sands in the bottom of the river. In addition, the temperature of the water did not peak as high or low as that of the river and the dissolved solids content of the water was more constant than that of the river. Also the bacteriological quality was improved so that only a nominal dosage of chlorine was necessary to assure its use for drinking purposes.

In summarization, artificial recharge, where applicable, serves several valuable purposes in the solution of water supply problems. Artificial recharge is an important method of storing run-off and flood waters,

which otherwise would be wasted, for use when needed during dry seasons when stream flows are low. It provides a means of reducing or eliminating the deleterious effects of overdevelopment of groundwater sources of supply, such as, an inadequate quantity and salt water intrusion, or it can be a means of supplementing an existing groundwater supply. The other purposes of artificial recharge listed are less important such as obtaining clear,cool water since reasonably economical alternates are available. For example, clear water can be produced from surface waters by established clarification and purification methods and water can be cooled by refrigeration methods. Whereas, for example, in sections of the arid western states, the surface stream flows may be essentially nil in dry seasons and groundwater is the only available source unless water is transported from great distances. Even in the eastern states where rainfall is more plentiful, surfaces sources may be inadequate in heavy centers of population and industry, especially during period of drought.

Although artificial recharge is a potential means of solving some water supply problems, each potential application must be evaluated to determine if it is physically and economically feasible.

The geological and hydrological conditions must be evaluated at each potential location for artificial recharge to determine the physical feasibility. Also, the recharge water must be investigated as to its adequacy; whether or not it is chemically compatible with the groundwater and does it require pretreatment to avoid clogging the soil. In addition, the method of recharge, most suitable for the application, must be selected and the economical feasibility must be determined.

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